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A CATHODE RAY TUBE WITH POST-ACCELERATION

by J. de GIER.

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In order to obtain a high scanning speed with a cathode ray tube it is desirable to raise the accelerating voltage for the electrons as high as possible. In the ordinary models this attempt is limited because of the fact that the dimensions of the tube would have to be increased with the voltage and the deflection sensitivity would decrease. These disadvantages are very much reduced when post-acceleration is applied *i.e.* when the electrons are accelerated anew with the help of an extra electrode after they have passed the deflection plates. By this means a considerably higher scanning speed can be attained without it being necessary to increase the dimensions of the tube, while in addition the sensitivity is not so unfavourably affected as when the electrons have already attained their final velocity before they pass the deflection system. In this article the post-acceleration tube DN 9-5 is described which has been developed from the cathode ray tube DN 9-3. The electrode for post-acceleration can be given a voltage of 5 000 volts with respect to the cathode. A maximum scanning speed of 24 km/s. is hereby obtained. A detailed account is given of the way in which the post-acceleration electrode affects the deflection sensitivity of the cathode ray tube and of the way in which the distortions caused by the post-acceleration electrode are combatted.

A very important quantity for the characterization of the performance of a cathode ray tube is the maximum scanning speed, *i.e.* the maximum speed at which the light spot may move on the screen of the cathode ray tube in the case of a phenomenon occurring only once, in order to be visible or to be recorded photographically. In an earlier article in this periodical¹⁾ an account was given of the electrical tube properties and factors of the photographic process which determine the maximum scanning speed. As to the electrical tube properties, in order to obtain a high scanning speed, provision must be made for a high beam current, a small diameter of the spot and a high speed of the electrons which strike the fluorescent screen. In the photographic method, moreover, it is chiefly a question of a large relative aperture of the photographic objective and the greatest possible reduction in size of the photograph.

In order to illustrate the scanning speeds which can be obtained with ordinary types of cathode ray

tubes, an investigation may serve which was carried out on the cathode ray tube DN 9-3 (a tube with a screen diameter of 9 cm, which is employed in the cathode ray oscillograph GM 3 152). The accelerating voltage in this case amounted to 1 000 volts, the current in the beam to 20 μ A. The oscillogram was a reduction of the image in the ratio 1 : 4, while a lens with an aperture 1 : 2.2 was used, such as is found in many of the miniature cameras at the present time. The film used was Agfa Isopan. It was found that the greatest scanning speed with which an easily visible blackening of the film is obtained amounts to 850 m/s. This means that a phenomenon with a duration of 10^{-5} sec can be represented by a line of 8.5 mm arc length. In many technical applications this will be adequate, but for the investigation of breakdown phenomena, surge voltages, etc., where processes with a duration of 10^{-6} or 10^{-7} sec may occur, considerably higher scanning speeds are required.

The obvious method of solving the difficulties is by trying to increase the scanning speed by choosing more favourable values for the above-mentioned factors which determine the scanning speed. An increase in the scanning speed by a reduction in the diameter of the spot (0.8 mm) is, how-

¹⁾ J. F. H. Custers: The recording of rapidly occurring electrical phenomena with the aid of the cathode ray tube and the camera, Philips techn. Rev. 2, 148, 1937. On the subject of a new instrument for measuring scanning speeds see: L. Blok, Philips techn. Rev. 3, 216, 1938.

ever, practically impossible, since the constriction of the beam is limited by the mutual repulsion of the electrons. This repulsion is also the cause of the fact that no success is achieved by increasing the beam current; this would result in an increase in the diameter of the spot, which is undesired in connection with the sharpness of the oscillogram and, moreover, has an unfavourable effect on the scanning speed, which is inversely proportional to the spot diameter at a given light intensity.

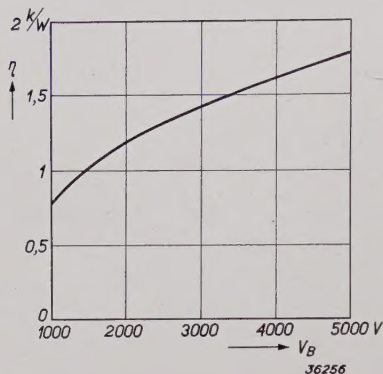


Fig. 1. Efficiency η of the conversion of electrical energy into light (c.p./watt) as a function of the accelerating voltage V_B of the electrons which strike the fluorescent screen.

It is indeed possible to obtain a very appreciable improvement by increasing the accelerating voltage. In the first place, with constant current more power is converted into light, and proportional to this power the maximum scanning speed also increases. In the second place the efficiency of the conversion also becomes greater (see *fig. 1*), so that the amount of light produced with an increase of the voltage from 1 000 to 5 000 volts, for instance, is not five times, but more than ten times as great. In the third place the mutual repulsion of the electrons becomes continually less effective with increasing velocity, so that the light spot on the screen can be reduced in size, which, as we have seen, means an increase in the scanning speed obtained. In the fourth place, in certain cases when there is no particular need of this reduction in spot diameter, it would be possible to increase the current with increasing voltage, whereby the power, and thus also the scanning speed, would increase still more. Practically, an increase of the voltage by a factor 5 means an increase in the maximum scanning speed by 25 or 30 times.

Any considerable increase in the accelerating voltage is, however, not immediately possible in cathode ray tubes of small dimensions such as are used in portable types of cathode ray oscillographs. The insulation of the leads in the tube DN 9-3 is calculated for potential differences of 1 000 or

perhaps 1 200 volts. For 2 000 volts the base would have to have dimensions which cannot be considered for a portable instrument. Another, fundamental, objection to the increase in voltage is that the deflection sensitivity of the tube is hereby decreased, since the deflection of the cathode ray by a given deflection voltage is inversely proportional to the accelerating voltage. With an accelerating voltage of 1 000 volts the deflection sensitivity of the tube DN 9-3 is 0.4 mm/volt for the first set of plates and 0.3 mm/volt for the second, and these values must not be decreased too much by the increase in the accelerating voltage.

Principle of the post-acceleration tube

It is possible to overcome the above difficulties by making the acceleration take place in two stages instead of directly. The focussing system forms an electron beam with a velocity corresponding, for instance, to 1 000 volts. This beam passes successively the systems for vertical and horizontal deflection and then undergoes a second acceleration with the help of an electrode at a considerably higher potential, and at such a distance from the other electrodes that the insulation does not present insuperable difficulties. If, in addition, this second acceleration, the so-called post-acceleration of the electron beam, is made to take place in such a way that the direction of the beam remains unchanged, the second objection to the high voltage, decrease in sensitivity, is eliminated.

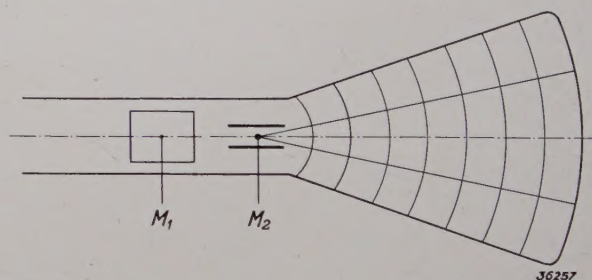


Fig. 2. Principle of the post-acceleration without decrease in the deflection. Behind the deflection system there is an accelerating field whose equipotential surfaces are perpendicular to the trajectories of the electrons.

If we wish to accelerate the electrons which leave the deflection system without changing their direction, we must excite an electric field whose equipotential surfaces are perpendicular to the direction of the beam of the electrons at every point (see *fig. 2*). The cross sections of these equipotential surfaces in the horizontal plane would be circles with the centre M_1 , while in the vertical plane they would be circles with the centre M_2 .

In order to give the potential field in the whole

space the desired character, it is sufficient to cause the potential at the boundaries of the tube to vary in the correct way. This can be done by covering the walls of the tube with ring-shaped conducting strips, corresponding to the lines of intersection of the equipotential surfaces and the wall of the tube, and bringing these strips to the desired values of the potential (see *fig. 3*). In practice it has been

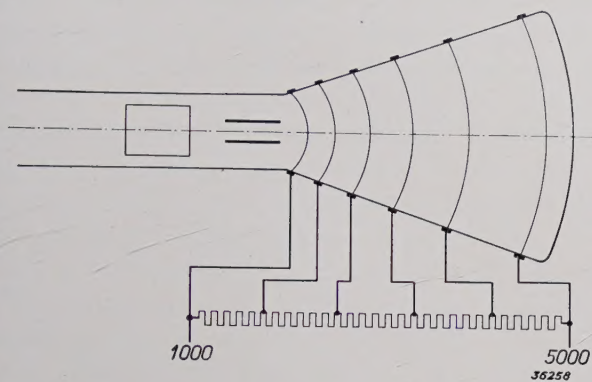


Fig. 3. A given prescribed potential field can be realized by fixing the extreme values of the potential in a suitable manner.

found that such a complicated structure is unnecessary; instead of a large number of narrow strips, two broad coatings can be used: one at 1 000 volts, *i.e.* the potential which determines the speed of the electrons in the deflecting system, and one at 5 000 volts, for instance, which determines the speed at which the electrons impinge on the fluorescent screen.

The principle of this arrangement is shown in *fig. 4*. As may be seen from the equipotential sur-

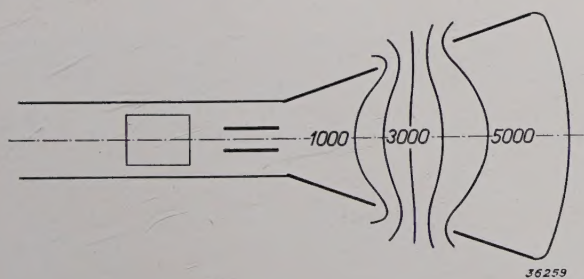


Fig. 4. Principle of the post-acceleration tube. This may be considered as a simplification of *fig. 3*. The equipotential surfaces do not have exactly the desired form.

faces which hereby occur, the potential field has not exactly the desired character, and it is found that the post-accelerating field also deflects the electron trajectories, so that the sensitivity of the tube decreases slightly with increasing post-acceleration. We shall examine this phenomenon more closely because the attempt to combat it has had some influence on the construction of the new tube.

The lens action of the post-acceleration electrode ²⁾

In order to describe the motion of an electron in an electrostatic field qualitatively, use can often be made of an analogy between the trajectory of an electron in a potential field and the path of a light ray in a medium with an index of refraction which is in general variable. This analogy is as follows. If an electron at a point at zero potential has the velocity v_0 , and if, to every point in space, an index of refraction given by the following is ascribed:

$$n = \sqrt{\frac{v_0^2 + \frac{2e}{m} V}{v_0^2}}, \quad \dots \quad (1)$$

where V is the potential at the point in question, then a light wave which is emitted in the same direction as the electron follows the same trajectory as the electron ³⁾.

If we apply this proposition to the space behind the deflection system of the post-acceleration tube, we see that, after passing the deflection system in *fig. 4*, the electron beam first passes through a number of less strongly negatively refracting planes. To make this clear, the optical system which is formed in this way is given in *fig. 5b*. In this figure the positive and negative refracting surfaces lying close together are indicated by a single surface.

The system already shows some similarity with an optical lens, with this difference, that the index of refraction is greater in the image space than in the lens itself. We may, however, adopt more normal relations by setting the index of refraction in the image space equal to unity once more, and at the same time changing the curvature of the last lens surface so that the refractive properties of the lens remain the same. The lens represented in *fig. 5c* is then obtained, with a convex and a concave surface. The vertical planes H and H' in *fig. 5c* indicate the main planes of the lens and show that the lens must be imagined somewhat closer to the deflection system than the middle of the open space

²⁾ The following considerations were first given by W. Rogowski and H. Thiele: Über die Nachbeschleunigung bei Braunschen Röhren, *Arch. Elektrot.* **33**, 411, 1939.

³⁾ This proposition can most easily be deduced from the analogy between the so-called principle of least action of Maupertuis:

$\int \sqrt{T} ds = \text{minimum}$ for the trajectory actually described of a mass point (T kinetic energy, ds element of trajectory)

and the proposition of Fermat for optics:

$\int n ds = \text{minimum}$ for the path chosen by the light (n index of refraction).

*The quantity under the radical sign in equation (1) is, except for a factor, nothing else than the kinetic energy, from which the analogy between electron trajectory and light ray immediately follows.

between the coatings. We shall use this optical picture further in the discussion of the influence of the post-acceleration on the deflection of the beam.

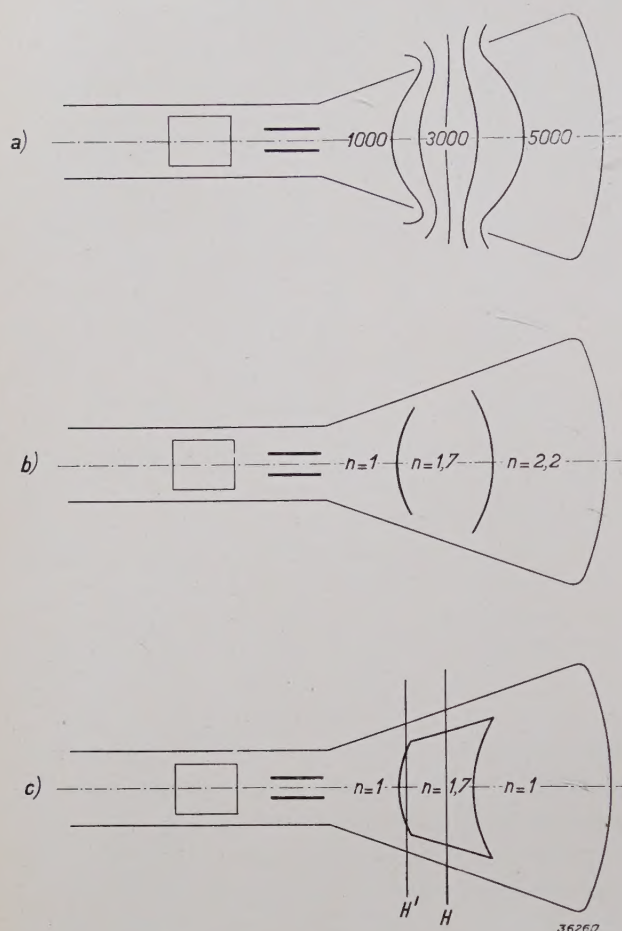


Fig. 5. Lens action of the post-acceleration field.

- Form of the equipotential surfaces.
- Lens, which would have the same refracting effect on a light ray as the electric field on the electron trajectories.
- Lens, derived from b) by reversing for the second surface both the sign of the curvature and the sign of the change in index of refraction, so that the refraction of this surface remains the same. The optical analogy with the potential field thus obtained is a lens in air. H and H' are the main planes of the lens.

It is very important for the sensitivity of the cathode ray tube at what point this lens is situated and how strong it is. Figs. 6a-f make this clear. In cases *a* and *b*, which most closely approach the form actually chosen, the lens is quite weak, but still strong enough to cause the deflection of the beam to decrease appreciably. Fig. 6c represents a considerably stronger lens. The residual deflection of the beam now becomes very small. It is therefore clear that the decrease in sensitivity upon application of post-acceleration need by no means always be smaller than with a direct acceleration of the electron beam. It may even happen that no sensitivity at all remains (fig. 6d), or that the sign of the deflection is reversed by the post-acceleration

lens (fig. 6e). In the last case it is even possible theoretically to increase the strength of the lens so much that the absolute value of the deflection becomes greater than the original deflection in the absence of post-acceleration (fig. 6f). In practical cases the possibilities offered by *e* and *f* cannot be used directly because a very strong deflection of the beam is always accompanied by distortions. We are thus concerned with cases *a*, *b* and *c* where the sensitivity is decreased by the action of the post-acceleration, and we can only try to choose

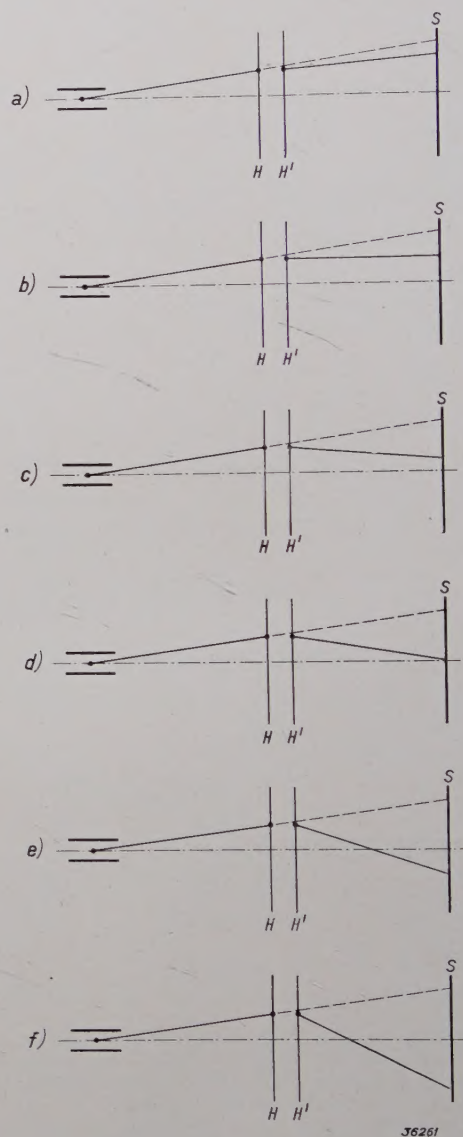


Fig. 6. Influence of the post-acceleration lens on the deflection of the electron beam by the deflection plates.

- a) and b) Weak post-acceleration lens. The deflection of the electron beam is only slightly decreased.
- c) and d) Strong post-acceleration lens. The deflection of the electron beam is considerably diminished and disappears in the last case entirely.
- e) and f) Very strong post-acceleration lens. The deflection of the electron beam has a direction on the screen opposite to that caused by the deflection plates. In the last case the absolute value of the deflection caused by the presence of the post-acceleration lens is increased.

the conditions in such a way that this decrease is as slight as possible.

In the first place the lens itself must be made as weak as possible. The strength of the lens increases with increasing post-acceleration voltage, so that in practical cases this voltage will not be made higher than necessary for the particular phenomenon to be projected on the screen. The absolute value of the voltage is not actually the determining factor for the strength, but the relation between the voltages of the first and last coating. It might therefore be imagined that the lens could be made weaker by increasing the voltage of the first coating. In doing this, however, as already mentioned, one is limited to about 1 000 volts in the case in question due to considerations of a structural nature.

When the voltages of the coatings are chosen, the strength of the lens can still be affected by suitable construction of the electrodes. To make the lens as weak as possible the diameter of the electrodes must be as large as possible. By constructing the electrodes in the form of wall coatings, this condition is satisfied, the diameter of the tube is naturally limited by the size of the oscillograph apparatus. Furthermore, the strength of the lens increases with increasing distance between the coatings and this should therefore be taken as small as possible. A practical limit is set to this by the requirement of sufficient insulation. This point will be considered further in the following.

Finally an attempt may be made to choose the position of the lens in the tube so that its deflecting effect is as small as possible. In this respect a certain

amount of variation is found to be possible with a given strength of the lens.

If for a weak lens the magnitude of the deflection finally obtained is calculated as a function of the position of the lens, it is found that the deflection has a minimum when the lens is situated symmetrically with respect to the point halfway between the deflection plates and the point at the centre of the screen. Every displacement from this plane of symmetry thus improves the sensitivity. The lens might for example be placed as close as possible to the screen. This displacement is, however, limited by the fact that, as we have seen, the lens is always further away from the screen than the open space between the coatings, which themselves must be applied at not too small a distance from the screen, since otherwise the potential does not attain the desired high value over the whole surface of the non-conducting screen. If one attempts, conversely, to displace the lens as far as possible towards the deflecting system that difficulty does not arise, but the equipotential surfaces of the post-acceleration field are then deformed by the presence of the field of the deflection plates, which is not rotation symmetrical, and the lens exhibits an astigmatism. This difficulty, however, is found not to be unconquerable, so that the second method is to be preferred. In the discussion of the practical construction we shall see how the astigmatism is corrected.

Construction of the post-acceleration tube

Fig. 7 is a photograph of the post-acceleration

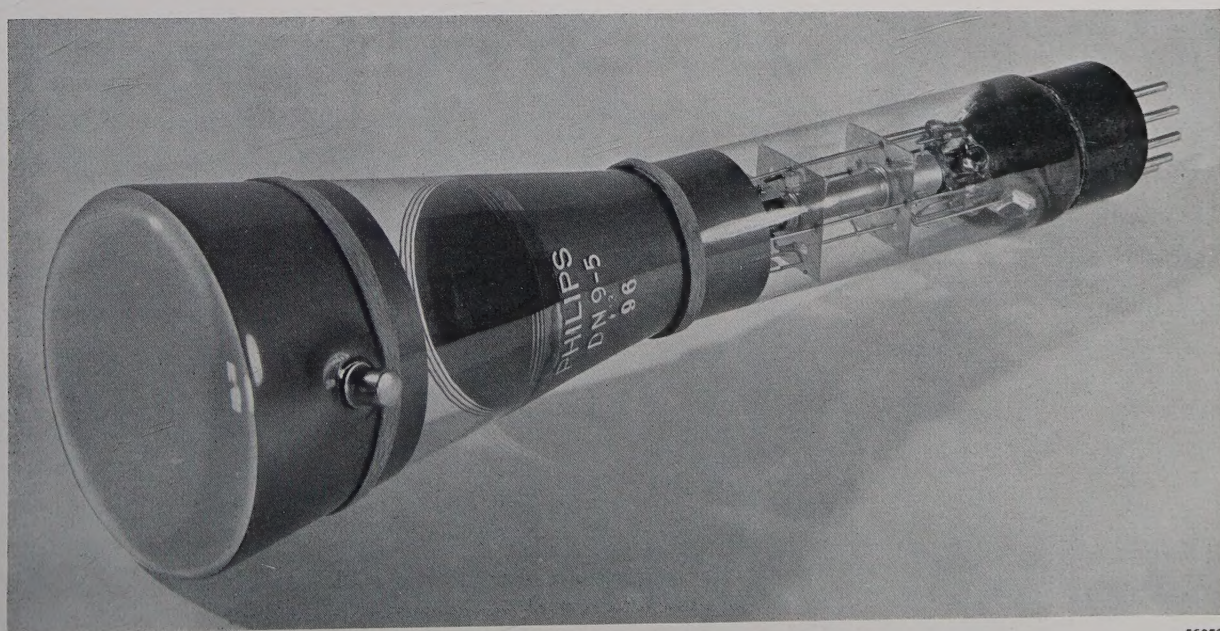


Fig. 7. Photograph of the post-acceleration tube DN 9-5.

tube DN 9-5. Both the external dimensions and the internal electrode system correspond in the main to those of the tube DN 9-3 previously de-

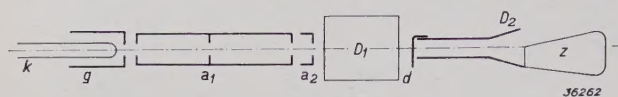


Fig. 8. The internal cathode system of the cathode ray tube DN 9-5 with post-acceleration. *k* cathode, *g* regulatory electrode, *a*₁ focussing anode with voltage of about 275 volts, *a*₂ acceleration anode with voltage of 1000 volts, *D*₁ and *D*₂ deflection system, *d* rods for combatting trapezium distortion, paddles for combatting astigmatism and distortion due to the post-acceleration.

scribed ⁴⁾ of the cathode ray oscillograph GM 3 132. The most important difference is that the conducting coating on the inner wall of the tube is split into two coatings *A* and *B*, of which part *A* as in

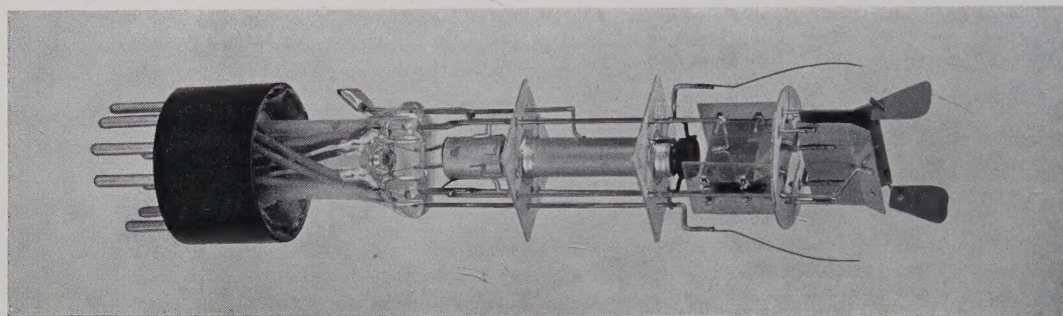


Fig. 9. Photograph of the internal system of the post-acceleration tube.

tube DN 9-3 is connected to the anode of the focussing system, and is at a potential of 1 000 volts with respect to the cathode, while coating *B* has a separate lead to the outside to which any desired voltage between 1 000 and 5 000 volts can be applied ⁵⁾.

Both coatings consist mainly of a deposit of graphite on the inside of the glass. In order to make the edge of electrode *A* smoother in order to increase the flashover voltage, at the edge the graphite was replaced by platinum; in addition, in front of this edge lie several ring-shaped stripes of the platinum deposit which are not brought to a definite potential, but are free to become charged. These stripes influence the distribution of potential between the coatings in such a way that the breakdown potential becomes still higher. In this way

it was made possible for the voltage on electrode *B* to be raised to 5 000 volts without danger of flash-over between the two coatings.

The internal electrode system of the post-acceleration tube is shown diagrammatically in fig. 8 while fig. 9 is a photograph of the system. The electrons which leave the cathode *k* and pass the regulatory electrode *g*, then they are accelerated by the tubular anodes *a*₁ and *a*₂, the first of which is at an adjustable focussing voltage of about 275 volts and the second at the acceleration voltage of 1 000 volts.

The electron beam which leaves the focussing system passes the two sets of deflection plates *D*₁ and *D*₂ which serve for vertical and horizontal deflection, respectively, of the electron beam. The system *D*₂ has two rods *d* which serve to eliminate the so-called trapezium distortion which occurs

when a non-balanced voltage is applied to the second set of deflection plates ⁶⁾.

Due to the post-acceleration two other types of distortion also occur, namely:

- 1) an astigmatism of the electron beam, which has already been mentioned in connection with the choice of position for the post-acceleration lens;
- 2) a barrel-shaped deformation of the oscillogram.

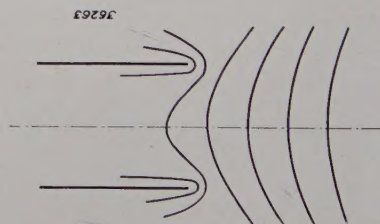


Fig. 10. The equipotential surfaces of the post-acceleration field are compressed, at it were, which leads to astigmatism.

⁴⁾ J. D. Veegens, Philips techn. Rev. 4, 210, 1939.

⁵⁾ For this purpose the convenient supply apparatus GM 4 198 may be used, which gives an adjustable voltage of from 0 to 5 kV. This supply apparatus is adapted to the measuring apparatus provided with the post-acceleration tube, namely the cathode ray pressure indicator GM 3 154 and the cathode ray oscillograph GM 3 156.

⁶⁾ In the customary application of the cathode ray tube the horizontal deflection is obtained with the help of a saw-tooth generator. In the case of the cathode ray oscillograph GM 3 152 this gives a non-balanced voltage, i.e. the potential of one terminal of the generator is constant, while that of the other varies. In order not to obtain trapezium distortion, the terminal which has a variable potential must be connected to the plate bearing the rods.

Both phenomena may be ascribed to the fact that the potential field of the post-acceleration electrode penetrates between the deflection plates and here undergoes a deformation like that sketched in *fig. 10*. The equipotential surfaces are more sharply curved by the set of plates D_2 in the plane of the drawing, thus in the horizontal plane, than in the vertical plane, which means in optical language that a cylindrical lens is placed in front of the actual post-acceleration lens.

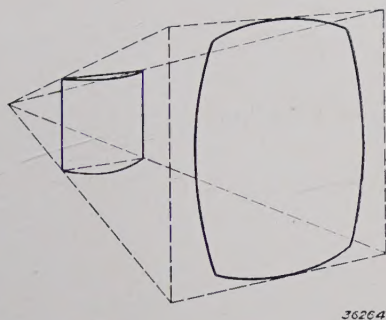


Fig. 11. Action of an astigmatic lens (cylindrical lens). An originally rectangular beam is compressed in one direction and in addition given a barrel-shaped distortion.

This cylindrical lens strengthens the electron lens in the horizontal plane, so that the beam no longer has a focus point on the screen, but a focus line. Moreover, it deforms the oscillogram in the way shown in *fig. 11*: in the first place it decreases the sensitivity of the system in the direction of the time base, and in the second place it leads to a barrel-shaped distortion of the oscillogram.

The astigmatism and the consequent distortion can be combatted by providing a plate of set D_2 with paddle-shaped appendages (see *fig. 9* and more clearly *fig. 12*). These paddles provide an extra focussing of the beam in a direction perpendicular to the extra focussing by the set of plates D_2 , and thus combat the astigmatism. The paddles are made so large that the astigmatism is just eliminated, the barrel-shaped distortion is then also found to have disappeared.

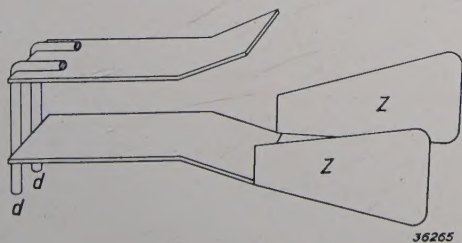


Fig. 12. The second system of deflection plates (D_2) with rods d and paddles z .

Properties of the post-acceleration tube

Focussing voltage

Fig. 13 shows the variation of the focussing voltage with the post-acceleration voltage. As has already been mentioned in the discussion of the

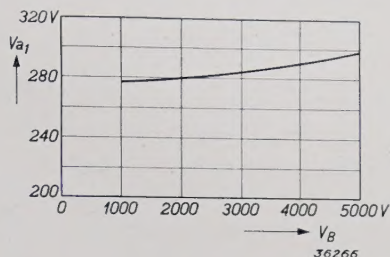


Fig. 13. Variation of the focussing voltage, which must be applied to the anode a_1 to obtain a sharp spot, as a function of the voltage of the post-acceleration electrode with respect to the cathode.

astigmatism, the post-acceleration lens also has a focussing action on the beam. If the tube is switched on without post-acceleration, and then focussed, the focussing voltage of the electrode a_1 must be increased as soon as the post-acceleration is set in action. The strength of the lens a_1-a_2 is hereby made smaller, which is necessary to keep the sum of the lens strengths constant.

Deflection sensitivity

Fig. 14 shows the relation between the deflection sensitivity and the post-acceleration. The voltage

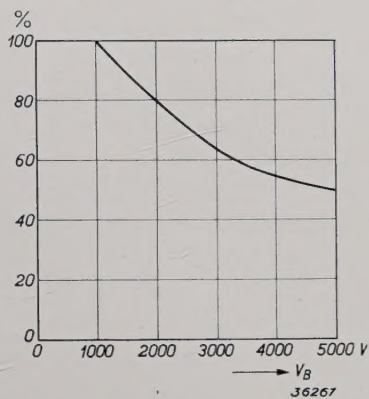


Fig. 14. Relative change in the deflection sensitivity as a function of the voltage of the post-acceleration electrode with respect to the cathode.

of a_2 and the coating A has been kept constant at 1 000 volts, while that of the second covering varies between 1 000 and 5 000 volts. The reduction in sensitivity is greater, the stronger the post-acceleration, as has already been shown.

With post-acceleration with a voltage of 5 000 volts with respect to the cathode the sensitivity amounts to one half of that without post-acceleration.

ation. If the same system were allowed to operate without post-acceleration with an anode voltage of 5 000 volts, the sensitivity would be $1/5$ of that at 1 000 volts, so that the post-acceleration is 2.5 times more favourable than a direct acceleration of the electron beam, as far as the sensitivity is concerned.

Size of image and definition

The reduction in the deflection sensitivity with increasing post-acceleration is naturally accompanied by a decrease in the maximum size of the image which can be attained without the oscillogram being distorted or cut off by the deflection plates. In designing the tube the primary aim was to give the tube the same sensitivity at a voltage on the screen of 1 000 volts (thus without post-acceleration) as that possessed by the tube DN 9-3. The deflection plates then also have such appropriate dimensions that the whole screen can be covered at 1 000 volts.

With a maximum post-acceleration (5 000 volts with respect to the cathode) this is, however, no longer possible. The largest oscillogram which can be obtained without deformation has dimensions of 40 by 40 mm, while the screen itself has sufficient area for an image 65 by 65 mm. This reduction in size of the image by no means involves a loss of details, however, since the fluorescent spot becomes sharper with increasing voltage. With constant beam current the reduction in size of the spot with increasing voltage on the screen is found to be about as great as the reduction in size of the oscillogram due to the decreased deflection sensitivity.

Scanning speed

Extensive tests have been carried out to determine the maximum scanning speed. Use was here again made of a camera with a lens aperture 1 : 3.2 and

Agfa Isopan roll film. If the post-acceleration electrode has a voltage of 5 000 volts with respect to the cathode, then with a fourfold reduction and a beam current of 20 μA the maximum recordable scanning speed is 24 km/s. At a voltage of 1 000 volts one obtains, under otherwise the same conditions, the scanning speed of 850 m/s already mentioned, so that there is a gain of a factor 25.

In laboratory measurements lenses with larger apertures, 1 : 1.5 for instance, will usually be available, and with such lenses a scanning speed of 100 km/s. can be obtained.

In conclusion, here are a few practical hints for the use of the post-acceleration tube.

The post-acceleration voltage must not be connected to the screen as long as the fluorescent spot is stationary. Due to the high power the spot would immediately burn in, which means that at the spot where the screen is struck by electrons of too high energy the sensitivity of the screen for electrons of low energy decreases appreciably. A straight line, also, *i.e.* a deflection with one set of plates offers no security against burning in. If, however, an A.C. voltage acts on both deflection plates then, with a beam current of 5 μA , for instance, the image may be kept continuously on the screen without there being a chance of burning in even at the highest post-acceleration voltage. (This beam current of 5 μA is sufficient to cause an image to appear on the screen which can also easily be seen in a well-lighted room). With short exposures one may go as far as 20 μA . For very rapid phenomena the regulatory electrode will simply be connected to the cathode, whereby a beam current of about 50 μA is obtained. One must then, however, work very quickly in adjusting the definition and desired size of image, since in that extreme case the image may only remain on the screen for a few seconds.

A PHOTOCELL WITH AMPLIFICATION BY MEANS OF SECONDARY EMISSION

by M. C. TEVES.

621.383.2

For the amplification of photocurrents use may well be made of secondary emission. The previously described electron multiplier, which is based on this principle, serves very well in the case of very weak photocurrents which vary at a very high frequency (television), but it is too complicated to be considered for simpler applications such as for sound film. A simpler construction which is suitable for this latter purpose is described in this article. The amplifier part consists of three stages with secondary emission, and, contrary to the case with the electron multiplier, it works entirely electrostatically, so that no external magnetic fields are necessary. About a hundredfold amplification is obtained, and thereby a photoelectric sensitivity of 2 to 3 mA/lm.

In almost all the cases where photocells are used, such as signalling and counting arrangements, sound film apparatus, television transmitting systems, etc. the currents obtained are too weak to be used directly, so that it is practically always necessary to amplify the current. The amplifier circuits familiar in radio technology are the first to be considered for this purpose. In addition it is possible to amplify the photocurrent in the tube itself to a certain extent by means of a rare gas filling, in which every photoelectron can free new electrons by ionization of the gas atoms. A third possibility is the application of secondary emission, *i.e.* the freeing of secondary electrons from an auxiliary anode which is struck by the primary photoelectrons. With a suitable choice of material for the auxiliary anode and of the voltage, every primary electron leads to the emission of 5 or 6 secondary electrons, so that the current can be amplified by a factor 5 or 6. If desired this process can be repeated a number of times, and in this way a very high amplification obtained.

The advantages of amplification by secondary emission over amplification with amplifier valves have already been explained in a previous article in this periodical¹⁾. They are mainly due to the fact that secondary emission causes no dark current, *i.e.* when the photocurrent is zero the secondary emitting plates also give no current. With an amplifier valve, on the other hand, a certain anode current flows even in the absence of the voltage to be amplified, and this current exhibits certain fluctuations (noise) which may be very disturbing upon amplification of very weak signals. Amplification by means of a gas filling, as far as noise is concerned, is less advantageous than amplification by means of secondary emission. Moreover, it is impossible to attain an amplification of any desired magnitude

with the help of a gas filling, and finally, due to the relatively slow motion of the positive ions, the current in the gas exhibits time-lag phenomena²⁾ which are manifested in a decrease in the amplification with increasing frequency, and which are already clearly observable at acoustic frequencies.

From these considerations it is found that not only for the amplification of photocurrents with a very high frequency (television), but also for sound film apparatus it may be advantageous to use photocells with amplification by secondary emission. A photocell for the latter purpose with three stages of amplification by secondary emission was developed in this laboratory and forms the subject of this article.

Requirements assumed in the design

The requirements which must be made of a photocell for use in sound film and the like are quite different from those made of the previously described photocell with secondary emission³⁾ (electron multiplier). For the tubes there referred to, which are used chiefly in television technology, it is not too important how extensive and complicated the construction is and how great are the pains taken in the setting and adjustment, since there is practically no other available solution which meets the requirement of linear amplification, independent of the frequency and free of noise, of the very weak photocurrents there prevailing, with their intensity fluctuations of very high frequency.

In the case of the sound film, on the other hand, where the necessary amplification can be obtained in many ways, the use of a photocell with secondary emission is only justified when the possible complications resulting from its use are less important than the simplifications which become possible in

¹⁾ See H. Rinia and C. Dorsman, Television system with Nipkow disc., Philips techn. Rev. **2**, 72, 1937, especially p. 74.

²⁾ See A. A. Kruithof, Philips techn. Rev. **4**, 48, 1939.

³⁾ See J. L. H. Jonker and M. C. Teves, Philips techn. Rev. **3**, 133, 1938.

other parts of the apparatus due to the greater strength of the photocurrent.

In the first place it is desirable that the necessary voltage of the photocell shall not be higher than the voltage which can be provided by the eliminator of normal sound film amplifiers (500 to 560 volts). Neither must it be necessary for the voltage to be exactly constant and precisely adapted to the cell, so that the cell can for instance be exchanged for a new one without it being necessary to readjust the apparatus. Finally it is desirable that the dimensions of the photocell shall be such that it can be built into a sound head of normal construction.

The limitation of the available voltage means either a limitation of the number of secondary emitting electrodes or a limitation of the available voltage per stage. In either case the amplification factor is limited. The best compromise lies at a voltage of about 150 volts per stage. This gives three stages of amplification by secondary emission, which thus require a voltage of 450 volts. The potential of the final anode must be higher by a certain amount than that of the last secondary emitting plate in order to draw all the electrons emitted by that plate to itself. It need not, however, be chosen higher than 650 volts.

The amplification to be obtained with three stages of secondary emission amounts to about a factor of 100. This means practically that in the construction of the apparatus connected to the photocell at least one amplifier valve can be omitted, while at the same time the noise level and the reproduction of high frequencies will be more satisfactory.

As to the second requirement (lack of sensitivity to fluctuations in the voltage), the previously described construction of the electron multiplier does not furnish a satisfactory solution. In that construction, which is given once more in *fig. 1*, the motion of the electrons is determined by the electric fields of the successive electrodes and by a magnetic field perpendicular to the plane of the figure. In order to

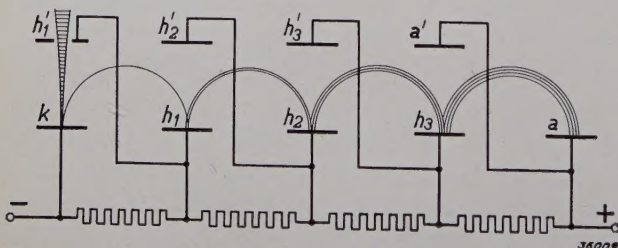


Fig. 1. Electron multiplier with electrostatic and magnetic deflection of the electrons. A light ray causes electrons to be emitted from the cathode k , which free secondary electrons from the auxiliary anodes h_1, h_2, h_3 , successively. The electrodes h_1', h_2', h_3' serve to provide the desired electric fields. The magnetic field is perpendicular to the plane of the drawing.

obtain the desired electron trajectories this magnetic field must be carefully adjusted as to strength and direction, and since the curvature of the trajectories depends upon the ratio between the intensities of the magnetic and electric fields, the potentials of the electrodes must be kept absolutely constant.

The obvious method of avoiding this difficulty is to use only electrostatic fields for the deflection of the electrons. When this is done the necessary fields can be provided by the electrode system of the cell, so that no external components must be regulated with respect to the cell. Moreover, with sufficiently low initial velocities of the electrons, their trajectories are then entirely determined by the relative values of the potentials of the different electrodes and not by their absolute values, which are then only of importance to the operation of the cell in as far as they influence the amplification factor of the secondary emitting plates.

In recent years a large number of types of electron multiplier systems which work purely electrostatically have been proposed, a few of which were described in the article referred to in footnote ³). These constructions have, however, certain disadvantages which are explained in the article mentioned, and which make it impossible for any of them to rival the constructions with mixed electrostatic and magnetic deflection of the electrons. In the meantime, however, a new and very simple construction has been proposed ⁴), which offers great advantages for our purpose.

Electrode systems with electrostatic focussing

Fig. 2 gives a cross section of the system with the electron trajectories obtained. The system consists of a number of electrodes with successively higher potentials which are so interlocked that the secondary electrons which leave a certain part of one electrode (shaded in the figure) are attracted by the following electrode and strike it within the corresponding region. In this way, in principle, any desired number of stages can be used, care must only be taken, by choosing a suitable shape for the first electrode, that the photoelectrons are actually focussed on the shaded part of the first auxiliary anode.

Beginning with the customary spherical photocathode, this can be done in the manner shown in *fig. 3*. Use is here made of the fact that the electric field between the photocathode and the anode has a focussing effect on the electrons, such that

⁴) V. K. Zworykin and J. A. Rajchman, Electrostatic electron multiplier, *Proc. Inst. Radio Eng.* **27**, 558-566, 1939.

a very much reduced image of the cathode appears on the anode. If an opening is made in the anode all the the photoelectrons will pass through it which are

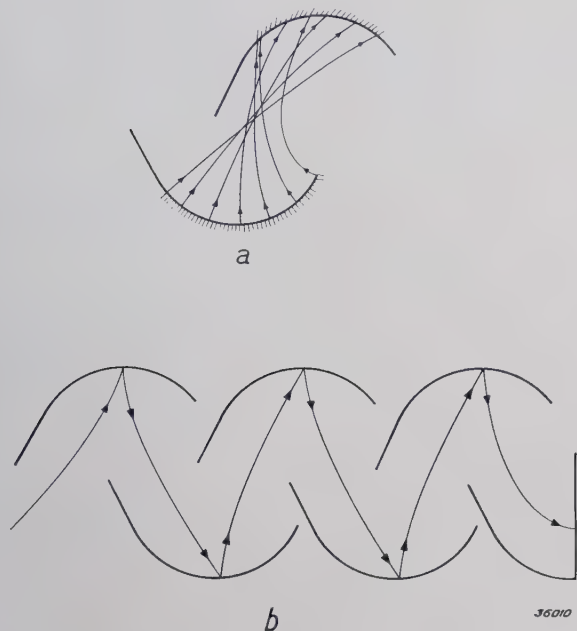


Fig. 2. a) Trajectories of the electrons between two successive electrodes of an electron multiplier with purely electrostatic focussing. The electrons which are freed on the shaded region of the lower electrode strike the corresponding shaded region of the upper electrode; the beam is therefore not broadened by passing through the successive stages. b) Five successive stages of an electron multiplier with electrostatic focussing.

emitted from a certain region of the photocathode, which region is considerably larger than the opening. In this way it is possible to combine the electrons from all parts of the photocathode which are important for direct illumination from the outside into a relatively narrow, homogeneous and well directed beam.

Thanks to this concentration of the electron beam it is possible to make the rest of the photocell, in which the triple amplification by secondary emission takes place, very small. The whole electrode system, consisting of the anode of the photocell, three secondary emitting auxiliary anodes and the final anode, is about 2 cm long, while the diameter of the spherical photocell is 4 cm. The area of the region on the cathode from which the photoelectrons reach the electron multiplier is about 1 cm². The light from the outside must therefore be concentrated on this spot. Part of the incident light is reflected by the photocathode on the other parts of the cathode. The photoelectrons freed by this scattered light also go to the anode, they do not, however, pass through the opening. In this way about $\frac{1}{4}$ to $\frac{1}{3}$ of the emission of the cathode is lost.

Further loss occurs because of the fact that not all the electrons follow the desired path from one secondary emitting electrode to the next. This is due to the fact that in the collision of an electron with the electrode, in addition to secondary electrons with a velocity from 0 to 15 volts (with a maximum in the velocity distribution at about 5 volts), directly reflected electrons also occur which have practically the same energy as the incident electron (150 volts). For these very fast electrons the system is not designed. They will also finally reach the last anode, but may skip one or more electrodes on the way, and therefore contribute less to the amplification of the anode current.

These losses show why the total amplification is less than the product of the amplification factors of the individual stages. If each of the secondary emitting electrodes emits an average of 6 electrons per incident primary electron, then the ratio between the current to the last anode and the current which enters the multiplier would theoretically be $6^3 = 216$, while actually it is about 130; the ratio of the current to the last anode to the total original photocurrent then amounts to about a factor 100.

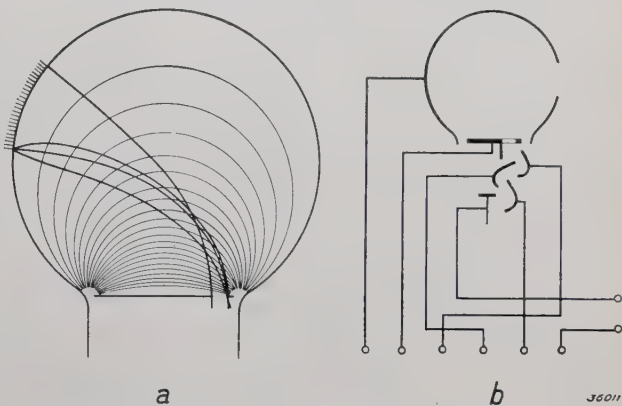


Fig. 3. a) Trajectories of the photoelectrons between a spherical photocathode and a plane anode (the thin lines are equipotential lines). The photocathode is projected in reduced size on the anode. The electrons freed from the shaded part of the photocathode pass through the opening of the anode and are multiplied in the succeeding multiplier system. b) Cross section of the system.

Construction of the photocell

The final construction of the photocell corresponds very closely to the diagram given in fig. 3. The photosensitive layer is deposited directly on the glass of the spherical upper part of the bulb, while the five other electrodes are assembled on a glass pinch which conducts the leads of these electrodes to the base. The connection of the photocathode is led out separately at the top. Fig. 4 is a photograph of the photocell with the amplifier stages in which

the various electrodes with the exception of the first anode can clearly be seen.

A special problem is the combination in one tube of the photoelectrically sensitive surface and the

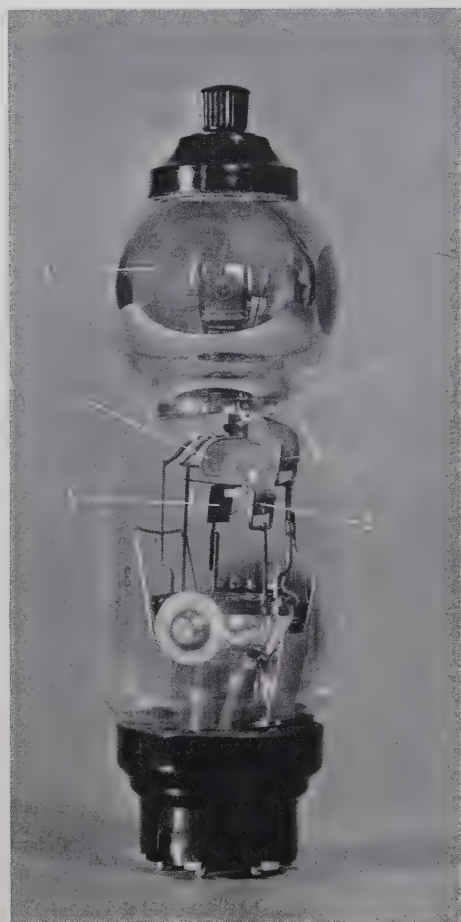


Fig. 4. Photocell with amplification by secondary emission. 1 Internal metallic deposit upon which the photo-electrically sensitive layer is deposited; 2 first anode; 3, 4, 5, secondary emitting auxiliary electrodes; 6 final anode. The current to the final anode is about 100 times as high as the photocurrent and amounts to 2 to 3 mA/lm.

secondary emitting surfaces. As was previously explained in the description of the electron multiplier⁵⁾, it is advisable to make these surfaces of the same material, since otherwise there is a danger that the surfaces layers will have detrimental effects upon each other while they are being prepared. As a possible solution the use of a silver underlayer covered with caesium oxide and adsorbed caesium was suggested. With such a layer the caesium oxide molecules have a very high secondary emission, while the adsorbed caesium atoms possess a high photoelectric sensitivity.

In order to increase to a maximum both the

secondary emission and the photoelectric sensitivity, the oxidation of the secondary emitting electrodes would have to be carried farther than that of the photocathode, namely so far, if possible, that all the adsorbed caesium was converted into caesium oxide. Such different treatment of otherwise identical electrodes, however, is accompanied by great difficulties, because there is a tendency for an equilibrium to be established during the preparation, at which equilibrium all the electrodes adsorb the same percentage of caesium. These difficulties have, however, been successfully overcome by treating the secondary emitting electrodes before covering with caesium oxide in such a way that they adsorb practically no caesium, so that when the photocathode and the secondary emitting cathodes are prepared together, no excess of caesium appears on the latter.

In this way we succeeded in combining in one tube a sensitive photocathode (20-30 $\mu\text{A}/\text{lm}$) and an electrode with high secondary emission (multiplication factor about 6 at 150 volts), without it being necessary to follow any other method of procedure in preparing the photocathode than is customary for ordinary photocells.

The choice of the voltages

If a large number of secondary emitting electrodes were to be used one after the other, it would be obvious that the voltage from one electrode to the following should be increased by the same value each time, for instance 150 volts. The voltage of the first anode must by experiment be so chosen that electrons which pass through the hole in this anode are concentrated as well as possible on the first secondary emitting plate of the amplifying system. The voltage of the last anode must be higher than that of all the other electrodes, but is further of no importance.

In our case of only three secondary emission stages, such a short system results that the first and the last electrode influence the field distribution over the whole system, so that the successive stages of amplification by secondary emission are not exactly identical. The best choice of voltage is then found to be slightly different from that according to a geometric series, and must be determined experimentally. This can easily be done by connecting the different electrodes to a potentiometer and changing its adjustment until the maximum current is obtained with constant total voltage and constant illumination of the photocell. The optimum mutual relations between the voltages found in this way is found to be independent of the total

⁵⁾ See the article cited in footnote ³⁾, p. 136.

voltage, which only determines the amplification. At a total voltage of 635 volts the series of voltage values given in *table I* was found to be the most satisfactory.

Table I

photocathode	0 volts
first anode	25 "
first secondary anode	300 "
second secondary anode	450 "
third secondary anode	580 "
last anode	635 "

The sensitivity obtained amounts to 2 to 3 mA/lm under the conditions indicated, which means that light fluxes above a few tenths of a millilumen are sufficiently intense to be registered with a single amplifier stage following the photocell. The maximum light fluxes available with sound film amount to about 20 millilumen. These give sufficiently great voltage variations on the output resistance

of the photocell to load the output stage of a sound-film amplifier fully. If photocells without amplification or with gas amplification are used, this is impossible, and pre-amplification must be employed, one stage with gas-filled photocells and two with vacuum cells.

Besides this structural advantage the photocell with secondary emission, as already mentioned, also offers advantages in the quality of reproduction. In the reproduction of Philips-Miller film, the sound track of which is of very high quality, the differences between the different kinds of photocells can clearly be heard. The secondary emitting photocell gives practically no distortion or noise. When a gas-filled photocell is used there is appreciable distortion and, moreover, an attenuation of the high tones. Due to the high amplification necessary with the vacuum cell the noise is disturbingly audible; the contribution of the first amplifier valve to the noise is in this case greater than that of the photocell.



X-RAY PHOTOGRAPHY WITH THE CAMERA

by A. BOUWERS and G. C. E. BURGER.

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While in the customary method of X-ray photography the film is pressed against a fluorescent screen placed in the beam of X-rays (contact photograph), a different method has recently been worked out in which the luminous X-ray image on the fluorescent screen is photographed with a camera. Since by this method the cost of a photograph is very much reduced, and the pictures obtained are not inferior to an ordinary fluoroscope image, the method is very well suited for series work in the detection of tuberculosis. The quality of the camera photograph obtained is compared with that of the contact photograph, and experiments are discussed which were performed in order to test the practical utility of X-ray camera photography. In conclusion the installation used in the Philips Medical Department is described and a short discussion is given of the problem of the danger of exposure to radiation.

In medical X-ray work two methods have long been used side by side: fluoroscopy, in which the X-ray shadow image of the patient is observed on a fluorescent screen, and X-ray photography in which the X-ray picture is recorded on a film which is pressed against the fluorescent screen. Finer details can generally be distinguished in the photograph than in the fluoroscope image, so that the doctor can form a sharper diagnosis from a photograph. Sometimes, however, particularly in series examinations of groups of people for the detection of tubercular lung lesions, it is not so much a question of the precise observation of a lesion, as of ascertaining that a lesion is present. In this case therefore fluoroscopy sufficed. This was very fortunate, since lung photographs made in the way described are quite expensive due to the large dimensions of the film required (normally 30×40 cm). Moreover, in the work of detection mentioned, fluoroscopy has the advantage that the doctor can project any possible diseased spots in different ways between the shadows of the skeleton in the image by turning the patient slightly in the fixed X-ray beam, and thus runs less chance of failing to detect any lesions hidden behind parts of the skeleton. In order to obtain the same security with the photographic method two or three photographs of each person in different positions would have to be taken, and the objection of expense would become even greater.

For these reasons series examinations for tuberculosis were confined to fluoroscopy, and the advantages which the photographic method offers with respect to objective documentation and the possibility of having a case judged by different doctors were relinquished.

In recent years another photographic method has now been developed ¹⁾ which makes it possible,

in detection work also, to profit by the advantages mentioned (documentation, etc.). In this method, so-called X-ray camera photography, the film is not placed at the point where the X-ray picture is formed, but the picture formed on the fluorescent screen is photographed by means of one of the normal miniature cameras at 2.4×3.2 cm, for instance. The costs of the photographic material, developing, archive space, etc. are hereby enormously reduced and no longer constitute an objection. This method has been applied for some time on a large scale by the Philips Medical Department for tuberculosis series examination.

The principle of the method is not new. Shortly after the discovery of X-rays, attempts were made to apply the principle, and from the beginning it has formed the basis of all experiments in X-ray cinematography of heart and lungs. The fact that the method did not immediately come into general use may be ascribed to the impossibility of obtaining a satisfactory quality of picture with the means then available. The quality of an X-ray picture depends upon the average density and the definition. It is found, however, as we shall explain later, that the increase in the definition always takes place at the expense of the density and *vice-versa*. While the compromise thus made necessary gave useful results in the case of ordinary X-ray photography ("contact photographs"), with X-ray camera photography the conditions for the compromise are much less favourable due to the loss of light in the photographic transmission, so that it was only the very high-speed lenses with their sharp definition and the sensitive, fine-grained films which have recently been developed for use in miniature photography, as well as the very much improved fluorescent screens, which have made X-ray camera photography practically possible.

We shall examine somewhat more closely the considerations mentioned above, by comparing the

¹⁾ M. de Abreu, Z. Tuberkulose 30, 70, 1938.

exposure conditions for the camera photograph and for the contact photograph. In *fig. 1* the two situations are represented schematically. For the contact photograph a film with an emulsion on both sides is used, and fluorescent screens (foils) are pressed against both sides of the film. In the camera photograph the fluorescence image is focussed on the film by a lens at a distance a with a

What are the consequences of this with respect to the definition? In the contact photograph there are three factors which contribute to the lack of sharpness U : that due to motion U_b , caused by the heart beat, the geometrical lack of sharpness U_g (half width of shadow), caused by the finite dimensions of the source of X-rays (the focus) and the foil lack of sharpness U_f , which is due to the

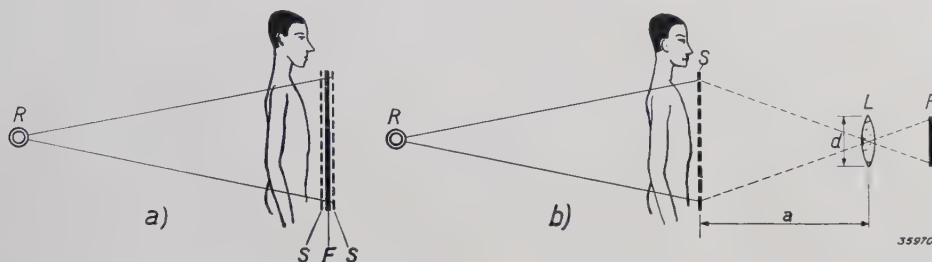


Fig. 1. Diagram of the situation in taking an X-ray contact photograph (a) and camera photograph (b). R source of X-rays (focus), S fluorescent foil or screen, F film, L lens.

diameter d and a focal distance f . While in the first case half of the radiation from each of the two fluorescent screens, or in other words, the total radiation of one screen, contributes to the blackening of the film, in the second case only the fraction captured by the lens is effective. This fraction is

$$k = \frac{\pi d^2/4}{4\pi a^2} = \frac{d^2}{16a^2}.$$

The quantity of light per cm^2 film surface is the deciding factor for the average density obtained, and since the camera photograph is reduced in the ratio a/f^2 , to obtain the same density on the camera photograph a total light radiation would be necessary n times as great as for the contact photograph, where

$$n = \frac{1}{k} \cdot \left(\frac{f}{a}\right)^2 = 16 \left(\frac{f}{d}\right)^2 \dots (1)$$

If we calculate with a relative aperture of the lens of $d/f = 1 : 1.5$, and this is approximately the maximum attainable practically at present, then according to (1) 36 times as much light is needed for the camera photograph as for the contact photograph²⁾.

²⁾ Strictly speaking this ratio is $a/f-1$, but as $a/f \gg 1$ we can use a/f for its value.

³⁾ In this simplified representation, no account is taken of the light absorption of the lens, which may be quite important particularly in lenses with large relative apertures. In the lenses here used it was about 30 per cent. This loss of light is partly compensated for by other effects. Altogether the ratio of 36 here given will be quite close to the truth. But even if the ratio were wrong by a factor 2, it is found from the following considerations that this has only a slight influence on the final result.

grain and the finite thickness of the fluorescent foil. The total lack of sharpness is

$$U = U_b + U_g + U_f \dots (2)$$

U_b is proportional to the exposure time, U_g to the width of the focus, U_f , as shown by tests⁴⁾, to the light yield of the foil. These same three quantities: exposure time, width of focus and light yield, also determine the total quantity I of the fluorescence light, I is proportional to each of them:

$$I \sim U_b \cdot U_g \cdot U_f \dots (3)$$

It is clear that with a given product of three variable quantities, their sum can be a minimum when all three are equal. The conditions for the photography (exposure time, size of focus, kind of fluorescence foil) are thus best chosen so that

$$U_b = U_g = U_f, \dots (4)$$

since in that case the total lack of sharpness U is a minimum, and is

$$U \sim \sqrt[3]{I} \dots (5)$$

so that the lack of sharpness of the camera photo-

⁴⁾ See A. Bouwers and W. J. Oosterkamp, Fortschr. Röntgenstr. 54, 87, 1936. In the discussion it is assumed that the exposure time is short compared with the period of the heart beat, so that the speed of movement of the particles in the lung is practically constant during the exposure, and that an X-ray tube with rotating anode is used. With a stationary anode the permissible specific focus loading depends also upon the time of loading, so that a more complicated formula takes the place of (3).

graph would be $\sqrt[3]{n}$ times as great as that of the contact photograph, where n is given by equation (1).

With the value of d/f given $\sqrt[3]{n}$ becomes 3.3. Thus a lack of sharpness of 3.3 mm in the camera photograph when it is enlarged to the same dimensions corresponds to a lack of sharpness of 1 mm in the contact photograph.

The ratio can, however, be made more favourable. We began with the assumption that the camera photograph must have the same average density as the contact photograph. Actually, however, there is no reason for trying to obtain the same density in the camera photograph, since it is usually observed by projecting it about life size, and films must be "thinner" for projection. This makes the required amount of light I smaller, and according to (5) the lack of sharpness also. Furthermore miniature films have in general a steeper gradation than the large X-ray films, so that it is possible to work with harder X-rays (which give less contrasty negatives), i.e. with higher voltages on the X-ray tube. Since the efficiency of the excitation of the X-rays then rises considerably, a smaller focus is large enough to give the same intensity of X-rays, and the geometrical lack of sharpness thus becomes smaller. Moreover, when the picture quality is chiefly determined by the lack of sharpness, it is advisable to reduce this lack of sharpness still more by slight compromises on other points, for instance by increasing the tube voltage slightly further, and then accepting the reduced contrast which results. In this way the geometrical lack of sharpness is still more reduced. The same effect is obtained by decreasing the distance b between

the focus and the fluorescent screen: for the same intensity of X-rays the width of the focus must be chosen so that $h \sim b^2$, and since the half width of shadow is proportional to h/b , for constant intensity this decreases proportionally with b . Of course a greater distortion of the shadow image must in this case also be accepted. Finally it is also advantageous to choose a somewhat longer exposure time than would correspond to condition (4). By this means the lack of sharpness U_g and U_f , which are constant over the whole photograph, are slightly decreased at the expense of a greater lack of sharpness due to motion U_b , which is, however, mainly confined to the neighbourhood of the heart and the large blood vessels. In the other parts of the lung where lesions most often occur there is a slight gain in sharpness.

In the camera photographs which are taken in the series examinations at Philips the usual tube voltage for the contact photograph of 50-70 kV is increased to 80-95 kV (the increased scattered radiations which hereby occur and which would lead to an undesired fogging of the photograph are made harmless by a thin scattered radiation raster); the distance b is reduced from 150 to 85 cm and the exposure time is 0.4-0.6 sec. instead of 0.1 sec. By this means the increase of the resulting lack of sharpness in the camera photograph is reduced to a factor 2. In order to give an idea of the excellence of the quality of the picture obtained in this way, an enlargement of a camera photograph, like thousands which have already been made here, and a reduction of a contact photograph of the same patient are reproduced side by side in *fig. 2*.

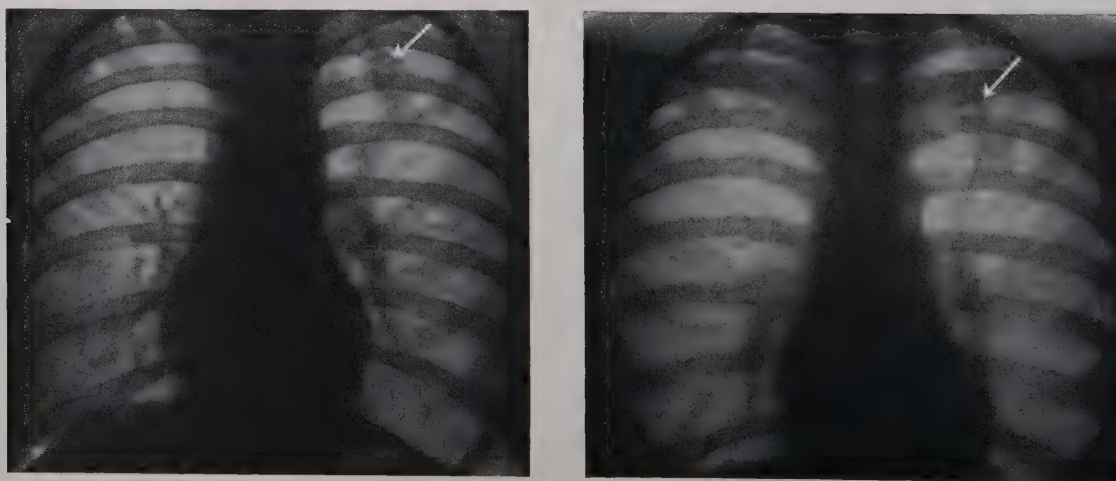


Fig. 2. Left: reduced contact photograph, right: enlarged camera photograph of the lung of the same patient. Under the left hand collar bone (see arrow) there is a small ring shadow which indicates an active tubercular process. This shadow as well as the blood vessels in the lung may also be seen very clearly in the camera photograph.

We have not yet spoken of two more causes of lack of sharpness which occur in the camera photograph: the grain of the film and the lack of sharpness of the lens, *i.e.* the size of the aberration circle in which a point is projected. Here again we encounter the incompatibility between density and sharpness. The grain of the film is larger with greater sensitivity, and the aberration circle of a lens increases with its relative aperture. Due to the great progress in miniature photography, however, with the film used by us with a sensitivity of about 17/10 DIN and with a lens with $d/f = 1 : 1.5$ the lack of sharpness is still small compared with that due to the above mentioned causes. We found a film grain varying from 5 to a maximum of 25 microns, and an aberration circle of our lens of 20-30 μ at the centre of the picture (this is somewhat larger at the edge). The lack of sharpness U may, however, amount to about 2 mm in the picture when brought to normal size, and to about 150 μ in the picture reduced about 13 times.

We shall not discuss the question of whether the X-ray camera photograph, which according to the above is not much inferior to the contact photograph, will not in time be able to replace the latter. The comparison here given, however, leads to the conclusion that camera photography can certainly take the place of the fluoroscopy customary in detection examinations, where less severe requirements are made with respect to the observation of details. Before we proceeded to the introduction of the method in series examinations, we tested its utility in practical cases by means of the following experiments⁵⁾.

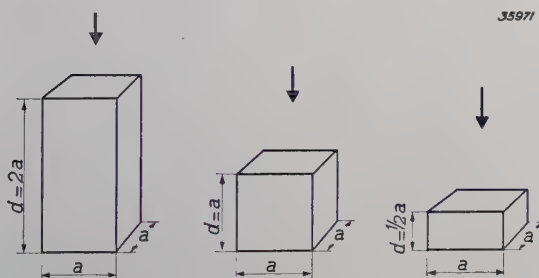


Fig. 3. Shape of the three objects which are used for the visibility tests with phantoms. The arrow indicates the direction of the X-rays.

In the first place the size was determined of the smallest object still just observable in the X-ray picture, by a method previously described in this periodical⁶⁾. The chest of the patient was replaced in these experiments by a "phantom" of "Philite" in which cavities of different dimensions were made to represent the objects to be observed. Since the

visibility increases with the contrast, which in turn depends upon the thickness of the object (dimension in the direction of the X-rays) the experiments were always done with three kinds of objects of the form shown in *fig. 3*. If the minimum thickness of the object required for visibility is plotted as a function of the width, the curves given in *fig. 4* are obtained. *Fig. 4a* relates to a normal phantom, *fig. 4b* to one in which unusually much scattered X-radiation occurred and which therefore represents the conditions occurring with stouter patients. It is found from the curves that smaller objects can generally be observed on the camera photograph better than in fluoroscopy, and that the difference in favour of X-ray camera photography is particularly pronounced with stouter patients.

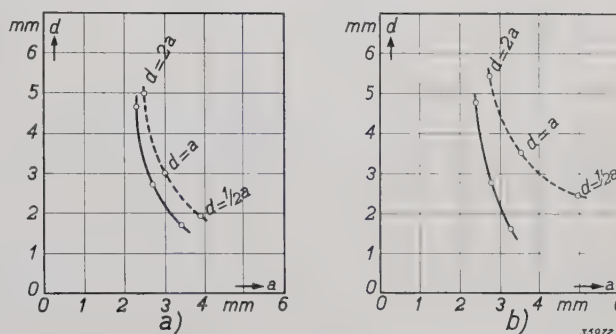


Fig. 4. The smallest object observable in a phantom in the fluoroscope image (broken-line curves) and on the camera photograph (full-line curves). The minimum thickness d required for visibility is plotted as a function of the width a . The points measured refer to the three types of object of *fig. 3*. a) Phantom corresponding to a normal patient. For the fluoroscopy the normal tube voltage of 54 kV was used. b) Phantom corresponding to stout patient. Due to the larger quantity of scattered radiation in fluoroscopy as well as in camera photography a so-called scattered radiation raster (Lysholm filter) was used. Moreover, the voltage was raised to 70 kV for the fluoroscopy.

Finally as a crucial experiment a comparison was made of the diagnoses which were made by different doctors independently of each other working according to the three methods of examination in a series of about 200 cases. In *table I* the results of this comparison are given. The cases are divided into three groups according to the seriousness of the lesions found in the lungs. Only in two cases of small inactive lesions did the X-ray camera photograph give less decisive results than the contact photograph and fluoroscopy. In eleven cases of large lesions fluoroscopy furnished less complete information. It must be remarked that for each patient exposures were made in three different directions, namely from back to front, front to back and obliquely through the body. From the last column of the table, in which the number of cases is indicated in which the second and

⁵⁾ G. C. E. Burgers, *Handelingen 27e Ned. natuurrk. en geneesk. Congres*, p. 194, 1939; *Maandschr. Kindergeneesk.* 9, 187, 1939.

⁶⁾ B. van Dijk, *Several problems of fluoroscopy*, *Philips techn. Rev.* 4, 114, 1939. More detailed in G. C. E. Burger and B. van Dijk, *Fortschr. Röntgenstr.* 54, 492, 1936; 55, 464, 1937; 58, 382, 1938.

Table I
Comparison of contact photograph (Co), camera photograph (Ca) and fluoroscopy (Fl)

Category of patients	Number of cases	Satisfactory agreement of all 3 methods	Fl. gives less than Co and Ca	Fl. and Ca. give less than Co	Ca gives less than Co and Fl.	Improvement by additional photographs
Large lesions	94	83	11	—	—	22
Few active lesions	17	17	—	—	—	16
Small inactive or no lesions	81	75	—	4	2	18

third exposure brought additional evidence to light, it is clear how important this is. In series examinations at Philips at least two camera photographs are always made.

The technique of the camera photographs is very simple. The camera is mounted at the end of a

light-tight photo tube with the fluorescent screen at the other end (see *fig. 5*) and is permanently focussed on the screen. The focussing is done with the fluorescence light itself, in order to be independent of any chromatic aberration of the lens. The shutter of the camera is superfluous and is therefore



Fig. 5. Apparatus for taking X-ray photographs with a camera. In the middle the X-ray tube in an earthed covering (walls which serve only to cut off scattered X-radiation are here removed). The patient stands upon a platform whose height can be adjusted, with his chest against the fluorescent screen to which a photo tube is connected with a light-tight joint. The camera is mounted at the end of this (extreme right). In the large box on the left is the high voltage generator which is operated from the stand shown in front of it. The person who makes the exposures need only see that the patient is in the right position and switch on the X-ray tube with a hand switch which also operates the film transport.

removed, while the film transport is coupled with the switch which operates the X-ray tube by a simple mechanism. In a box which may be seen to the left on top of the photo tube a card is inserted for every patient, upon which number, name, date and other data are written. The card is photographed on a corner of the X-ray exposure, so that mistakes are impossible.

One question which we should still like to touch upon is the danger from exposure to the rays. The dosage of radiation which the patient receives on his skin in making a camera photograph is 0.6-1.0 röntgen. In X-ray fluoroscopy, which takes about 1 minute, the dose is 2-3 r. If two or three exposures are made of one patient, he does not obtain a larger total dosage than in fluoroscopy. (The dosage is of course considerably larger than the tolerance dosage of 0.2 r per day, which is permissible without

injury to the health. Since, however, the fluoroscopy or photography of each patient only takes place at intervals of several months, the dosage of 3r mentioned can do him no harm.) For the operators the situation is much more favourable in the photographic method than in fluoroscopy. While in fluoroscopy the examining doctor must take care not to expose particularly his hands too much to X-radiation, in the photographic method, the person who makes the exposure, and this obviously need not be a doctor, can protect himself completely against the radiation by standing at a proper distance during the exposure, and if desired behind a lead or lead glass screen. In the arrangement used by us, for additional security a lead-covered revolving door was constructed (this was removed in fig. 5). When this door is not closed the X-ray tube cannot be switched on.

A TONE GENERATOR

by L. BLOK.

534.42 : 621.396.615.11

The tone generator GM 2 307, which can be used for the testing of loud speakers, amplifiers, cables, etc., is constructed on the heterodyne principle. The desired low-frequency signal is obtained by applying two oscillations of higher frequencies, one of which is variable, to a mixing valve. The choice of the frequencies is discussed, and it is explained how the frequency characteristic is made flat and how the deformation of the low-frequency signal is made small. The result is a characteristic which is practically flat from 30 to 16 000 c/s and an average deformation of 0.4 per cent with an output of more than 200 mW. At the expense of slightly greater deformation the output can be further increased to a maximum of 1 000 mW. By suitable arrangement of the components the shift of the frequency due to temperature fluctuations is very much restricted; upon heating up, the generator varies by a total of only about 20 c/s. The shift of the zero point of the frequency scale can be corrected in a simple way, and is checked by means of a cathode ray indicator. The influence of fluctuations in the mains voltage on the magnitude of the output voltage is made very small by means of compensation connections. In conclusion the different methods of application of the tone generator are discussed.

For measuring the frequency characteristic and the distortion factor of electro-acoustic installations or parts of such, for instance amplifiers, filters, cables, loud speakers, an instrument is needed which gives a pure sinusoidal voltage with a frequency variable over the whole acoustic frequency range. Such an apparatus, a so-called tone generator, may be realized in principle in very different ways. An oscillation of the desired frequency may for instance be generated mechanically, and then converted into an A.C. voltage by an electrodynamic system. Examples of this are the electrical tuning fork, which is often used for calibrations, and a tone

generator described some time ago in this periodical¹⁾, in which the oscillation was generated by means of a tuned string.

The region within which the frequency can be varied is practically always very limited with such mechanical generators, so that in order to cover the entire range of acoustic importance, i.e. about 30-16 000 c/s, a whole series of oscillators would have to be used. In this respect it is easier to excite the desired oscillation with a syren. With an optical syren, which has also been described pre-

¹⁾ Balth. van der Pol and C. C. J. Addink, Philips techn. Rev. 4, 205, 1939.

viously²⁾, sinusoidal oscillations can be produced whose frequency can be varied within wide limits by regulating the rate of revolution of the driving motor. Such an arrangement cannot, however, be considered for measurements on a technical scale, where an apparatus is required which is easy to use and easily transportable.

Satisfactory solutions of the problem are obtained when the oscillations are excited electrically, by means of tuned L - C circuits. But here also the most obvious method, namely of tuning the L - C circuit of an oscillator directly to the required frequency ($f = \frac{1}{2} \pi \sqrt{LC}$), is not practically possible, since very large condensers and coils would then be necessary for the lowest frequencies, while in order to cover the whole frequency range comprising 9 octaves, a whole series of oscillating circuits would again have to be used. Both difficulties are avoided when the heterodyne principle is applied. The oscillation with the desired frequency f is then obtained as a beat between two much higher frequencies f_1 and f_2 . The two oscillators for the production of these high frequencies require only small values of C and L , which, moreover, need to be altered only slightly to cause the desired variation of the differential frequency f . The Philips tone generator GM 2307, which will be described in the following, is constructed on this principle. It must be stated in advance that no attempt was made to satisfy the extreme requirements which may be made for certain laboratory experiments, but that the primary aim was to produce a simple portable apparatus, which is easy to use, permits a reasonable accuracy of measurement and which can be adapted to very divergent conditions of use.

Realisation of the heterodyne principle

In *fig. 1* the apparatus is shown diagrammatically. The two generators G_1 and G_2 provide the signals with the output frequencies f_1 and f_2 respectively. The beat with the differential frequency $f = |f_1 - f_2|$ is obtained in the same way as is customary in radio receiving sets on the heterodyne principle, by applying the two signals to a mixing valve M . The anode current of the mixing valve then contains, in addition to components with the frequencies f_1 and f_2 , components with the combination frequencies $f_1 + f_2$ and $|f_1 - f_2|$, as well as combination frequencies of the harmonics, $|mf_1 \pm nf_2|$. The combination frequency $|f_1 - f_2| = f$, with which we are concerned, is singled out by the low-pass filter F

and brought to the desired level by the amplifier V . The differential frequency f can be regulated by changing the frequency f_2 of the generator G_2 ³⁾.

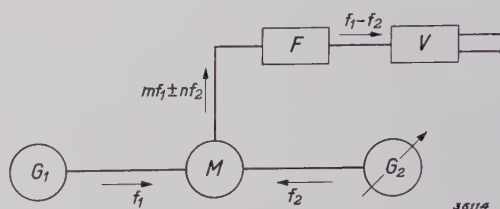


Fig. 1. Diagram showing the principle of the tone generator. G_1 constant, G_2 variable oscillator, M mixing valve, F filter, V amplifier.

While the maximum difference between the frequencies f_1 and f_2 is prescribed by the upper limit of the desired frequency range (16 000 c/s), the absolute sizes of f_1 and f_2 are not yet fixed. The advantage of the application of the heterodyne principle, namely that no large values or variations of C and L are required, however, becomes more pronounced the higher f_1 and f_2 are chosen. There is still another circumstance which makes it advisable to choose the highest possible values for these frequencies. The filter F must attenuate the signals f_1 and f_2 , which are much stronger than the desired signal $|f_1 - f_2|$ to levels so low that they may be neglected; this is done more easily the farther apart lie the highest frequency to be used $f_{\max}$ and the frequencies f_1 and f_2 , i.e. the higher f_1 and f_2 are made. The combination frequencies of the harmonics also, for instance $|f_1 - 2f_2|$, $|2f_1 - 3f_2|$, etc., then lie farther from $f_{\max}$, as shown in *fig. 2*, the higher f_1 and f_2 are chosen (the combination frequencies $|2f_1 - 2f_2|$, $|3f_1 - 3f_2|$, are naturally not displaced).

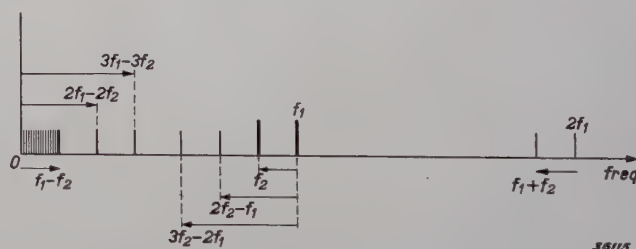


Fig. 2. Position of the original frequencies f_1 and f_2 and of the combination frequencies occurring $|mf_1 \pm nf_2|$.

On the other hand the frequencies f_1 and f_2 may not be raised indefinitely. The requirement must be made that the percentage variations of the oscillator elements necessary for regulating f shall be large with respect to the unavoidable small varia-

²⁾ J. F. Schouten, Synthetic sound, Philips techn. Rev. 4, 167, 1939.

³⁾ While in radio receiving sets the frequency of the local oscillator is so changed that the "intermediate frequency" obtained as beat with the signal received is constant, in this case it is the "intermediate frequency" which is varied.

tions due to temperature fluctuations, etc., since otherwise the frequency f when finally set might vary very much, which is of course undesired. At oscillator frequencies f_1, f_2 of the order of magnitude of 100 000 c/s, the variation of the frequency can still be kept within permissible limits relatively, while the construction of the filter does not yet offer any particular difficulties.

For setting the frequency zero, the two oscillators must have the same frequency, $f_1 = f_2$. Suppose that it is desired to make f_2 variable; must the differential frequency f then be obtained by raising or by lowering f_2 ? At first glance this seems a matter of choice; seen from the point of view of the variation of the frequency, however, there is only one answer to the question. The tuning of f_2 takes place in practice with the help of a constant condenser in parallel with a rotating condenser. The latter, which is in general quite sensitive to fluctuations in the humidity of the air, etc., contributes materially to the undesired variation in capacity, which is greater the greater the capacity to which the rotating condenser is adjusted. Now a given capacity variation is relatively most appreciable at a low differential frequency f . It is therefore advisable to arrange the apparatus so that for the lowest frequencies f the rotating condenser of G_2 stands at the smallest capacity, *i.e.* so that the differential frequency f is increased by increasing the capacity, thus by lowering the frequency f_2 of the tuning generator G_2 .

On the basis of the above considerations a frequency $f_1 = 100\,000$ c/s was chosen for the constant oscillator, while the frequency f_2 can be varied between 85 000 and 1000 000 c/s, in the tone generator GM 2 307. Moreover, the "constant" oscillator is not absolutely constant, but its frequency can be raised from 100 000 to 101 000 c/s. By this means a fine adjustment of the frequency f is made possible. The two condenser scales are calibrated directly in c/s, the frequency f is found by adding the readings of the two scales; the maximum value of f is thus $15\,000 + 1\,000 = 16\,000$ c/s⁴).

Distortion and frequency characteristic of the tone generator

In order to measure the distortion factor of any transmission element, the input voltage applied

to it, *i.e.* the output voltage of the tone generator, must be as free as possible of distortion. Furthermore, it is desirable for recording frequency characteristics, that the tone generator should give the same output voltage for all frequencies, *i.e.* that it should itself have a flat characteristic. In order to make clear how this condition is fulfilled in the tone generator here described we shall examine the process of the "mixing" of the frequencies f_1 and f_2 somewhat more closely.

If the voltage with the frequencies f_1 and f_2 applied to the two control grids of the mixing valve have the amplitudes V_1 and V_2 respectively, the amplitude of the anode A.C. obtained, having the differential frequency $f_1 - f_2$, may be written as follows:

$$I = S_c \cdot V_1, \dots \dots \dots (1)$$

where the so-called conversion slope S_c depends upon V_2 . The voltage V_1 of the constant oscillator is constant, the voltage V_2 of the variable oscillator changes more or less, however, with the frequency desired, so that S_c and with it I , would also change with the frequency. In the case of the mixing valve here used (the triode-hexode ECH 3) the conversion slope is found to change only very little with V_2 for voltages V_2 of the order of magnitude of 25 volts on the third grid. V_2 is thus made to fall in this voltage region.

As for the distortion, care must be taken that the frequencies $2f_1 - 2f_2 = 2f$ and $3f_1 - 3f_2 = 3f$, etc., which may still fall within the transmission region of the filter (F in fig. 1) connected behind the mixing valve, are only represented very weakly in the anode current of the mixing valve. The appearance of these frequencies may be ascribed to two main causes:

- 1) they are formed by the mixing valve as differential frequencies of the harmonics already present in the grid A.C. voltages applied;
- 2) they are formed by the mixing valve as higher combination frequencies ($mf_1 \pm nf_2$) of the grid A.C. voltages, even when the latter are purely sinusoidal.

It is clear that to avoid the first effect it is sufficient when only one of the two grid A.C. voltages gives as few harmonics as possible. The second effect is combatted by making the grid voltage V_1 small with respect to the voltage V_2 . Both conditions are realized by connecting a low-pass filter F_1 behind the oscillator G_1 , see fig. 3. The harmonics of f_1 are here eliminated, and at the same time the signal is brought back to the desired low level, about 0.1 volt. Both conditions could of course

⁴) The fact that the fine regulation is obtained by increasing f_1 is contradictory to the principle developed that f must be increased by lowering the oscillator frequency. The rotating condenser in G_1 necessary for the fine regulation of f_1 is, however, much smaller than that in G_2 , the shift in its capacity has therefore much less effect, while in this way it is made possible simply to add the readings of the two scales.

have been fulfilled without the filter, by only allowing the oscillator G_1 to oscillate with a very small amplitude, which also makes the distortion small. In that case, however, another cause of distortion would become evident, namely the reaction of the (very high) A.C. voltage V_2 on the oscillator G_1 , via the capacity between the two control grids. Due to the intermediate filter, which also has an attenuating effect in the opposite direction, the reaction is now limited.

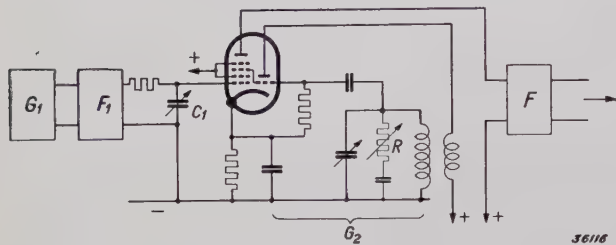


Fig. 3. A few details of the connections of the oscillators G_1 , G_2 and of the mixing valve. The filter F_1 removes the harmonics from the signal given by G_1 and weakens it to the desired degree, at the same time preventing a reaction of G_2 on G_1 . The condenser C_1 serves for any necessary regulation of the distortion and the output of the tone generator, the variable resistance R serves for a zero point correction of the frequency scale.

The last cell of the filter F_1 is indicated separately in fig. 3. It consists of a connection in series of a resistance and a condenser C_1 . The voltage on the latter is the grid A.C. voltage V_1 applied to the mixing valve. The apparatus is now so arranged that the capacity of the condenser C_1 can if desired be slightly lowered, whereupon a larger fraction of the total voltage acts on the elements in series. V_1 then becomes larger and a higher output is obtained, or with a given loading resistance a higher output voltage. While the output of the tone generator usually amounts to somewhat more than 200 mW, it may in this way, if necessary for special measurements, be increased to 1 000 mW. Of course the distortion also increases from the normal value of 0.4 per cent to 1 to 2 per cent. Conversely, when the distortion of 0.4 per cent is still too high for the required purpose, the voltage V_1 can be reduced by increasing the capacity of C_1 , and thus the distortion is reduced to a minimum of 0.25 per cent. The output of the tone generator then of course also falls to 100 mW. It would not in any case be possible to proceed in this way to reduce the output much farther, since the signal given by the mixing valve must be heard sufficiently high above the hum and noise level of the amplifier.

The amplifier V , which consists of three stages, works with a strong inverse feed-back, by which an amplification factor independent of the frequency

is obtained. Since also the magnitude of the signal given by the mixing valve, as already stated, scarcely depends upon the frequency at all, the frequency characteristic of the tone generator is practically entirely flat (see fig. 4). Due to the inverse feed-back the distortion in the amplifier is also kept small. The average values of the final distortion have already been mentioned.

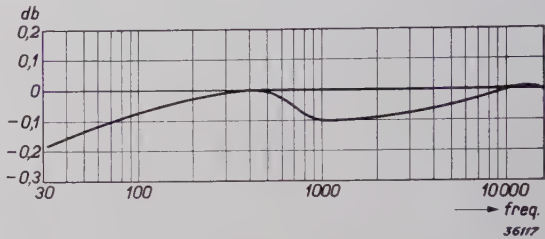


Fig. 4. Frequency characteristic of the tone generator.

The shift of the frequency

Several measures have already been mentioned above, which were intended to limit the shift of the frequency f as much as possible. We shall examine this point somewhat more closely. The main cause of a shift in the frequency is a variation of the temperature, particularly during the heating up after the tone generator has been switched on, which may take several hours before a constant temperature is reached. We may set the relative frequency change, which an oscillator undergoes with a temperature change t , proportional to t , and we call the proportionality factor the temperature coefficient a of the oscillator. In the case of the tone generator the change df of the desired frequency f is given by

$$df = df_1 - df_2,$$

thus
$$df = f_1 a_1 t_1 - f_2 a_2 t_2, \dots \dots (2)$$

where a_1 , t_1 and a_2 , t_2 are the temperature coefficients and the temperature variations of the two oscillators with the frequencies f_1 and f_2 , respectively. In general a_1 and a_2 will differ by a certain amount Δa , and in the same way t_1 and t_2 by Δt . Equation (2) thus becomes

$$df = f_1 a_1 t_1 - (f_1 - f)(a_1 - \Delta a)(t_1 - \Delta t),$$

or when Δa and Δt are sufficiently small with respect to a and t :

$$df = f a_1 t_1 + f_1 (a_1 \Delta t + t_1 \Delta a) \dots \dots (3)$$

The first term of this expression signifies an absolute frequency variation which increases with the tone frequency f required. In order to limit this variation the temperature coefficient and the tem-

perature increase of the two oscillators will be made as small as possible. In *fig. 5*, a photograph of the tone generator opened, it is possible to see what measures have been taken to limit the rise in tem-

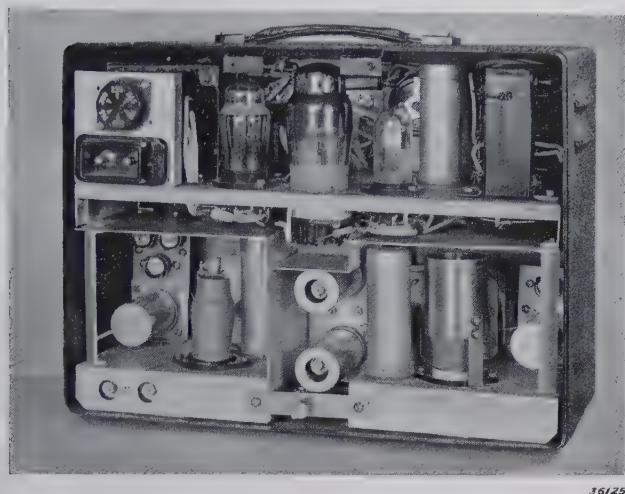


Fig. 5. Position of the components in the tone generator GM 2307; in the top compartment is the supply apparatus and the amplifier, to the right and left below, the coils and condensers of the oscillators.

perature of the oscillators. The supply apparatus section (transformer, rectifier, etc.) in which the most heat is developed is in a separate compartment in the upper half of the apparatus. The coils and condensers which determine the frequencies of the two oscillators are in the lower right and left-hand corners which remain relatively cool, due to the fact that a current of fresh air flows along the walls of the apparatus through the ventilation slits. In this way the temperature increase of the oscillators upon heating up is limited to about 6° . The temperature coefficients a_1 and a_2 amount to about 5×10^{-5} so that the first term of (3) causes a shift of $f \cdot 3 \times 10^{-4}$, i.e. at the highest frequencies about 5 c/s. Since the accuracy with which the frequency scales are calibrated and can be read is also limited, and in our case may involve an error of 100 c/s for instance at the highest frequencies (relative accuracy about 1 per cent), it would serve no useful purpose to reduce the shift in question still farther.

The second term of equation (3) is more important. This term expresses an absolute frequency variation which is independent of the desired frequency f . Due to the large value of f_1 (100 000 c/s) the second term is comparable in magnitude with the first term, even at the highest tone frequencies f , and at the low frequencies only the second term is important. To keep this term sufficiently small it is obvious in the first place that f_1 may not be chosen indefinitely high, as was stated at the be-

ginning of this article. Furthermore Δt and Δa should be made as small as possible, i.e. the two oscillators should be made to vary in the same way as far as possible. Δt is actually made very small by the symmetrical position in the cabinet⁵⁾ (see *fig. 5*). In this way the final result is such that within the first 15 min after being switched on the frequency does not shift more than 9 c/s, see *fig. 6*; in the succeeding hour it shifts about another 8 c/s, and in the final state, which is reached after several hours, the total frequency variation is about 20 c/s.

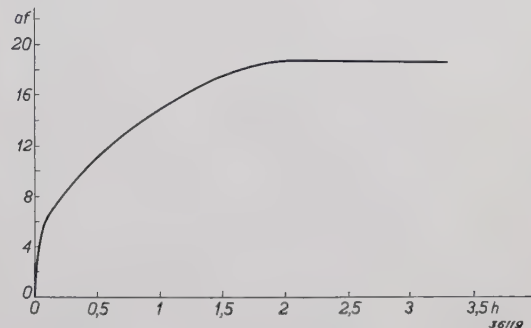


Fig. 6. The shift in frequency of the tone generator during heating up. df in c/s is plotted as a function of the time elapsed since switching on.

In order always to be able to make the calibration of the frequency scales agree with the frequencies actually obtained in spite of the shift (and any possible frequency variations upon fluctuations in the temperature of the surroundings), another small constant condenser, with an adjustable resistance R in series with it, is connected in parallel with the rotating condenser of the oscillator G_2 , see *fig. 3*. By varying R the small condenser is made to contribute more or less to the total capacity, and in this way the frequency f_2 is slightly affected. If the two rotating condensers are set at the zero position of their frequency scales, then by means of this fine regulation f_2 can be made exactly equal to f_1 , and thus $f = 0$ exactly. The equality of f_2 and f_1 is ascertained by means of a cathode ray indicator which works in the same way as the optical tuning indicator in radio receiving sets. The first stage of the amplifier consists of an amplifier valve EFM 1. This valve contains, in addition to the electrode system of an ordinary pentode, a fluorescent screen Fl (see *fig. 7*), upon which part of the electron current emitted by the cathode impinges. In the path of these electrons there is an electrode P

⁵⁾ It is also possible to give Δt and Δa different signs, and thereby to make the second term disappear entirely for a given temperature rise. For the rest of the temperature region, however, it is still desirable to make Δt and Δa small.

connected to the screen grid, which throws a "shadow" on the fluorescent screen, the size of which shadow depends upon the screen grid potential. This is influenced by the A.C. voltage on the control grid of the valve; at sufficiently low frequencies of the control grid voltage, *i.e.* when f_2 has been made equal to f_1 within a few c/s, the shadow on the fluorescent screen is seen to grow larger and smaller periodically. The resistance R is then adjusted so that the flicker becomes steadily slower and the shadow finally becomes stationary, which is a sharp criterion for the equality of f_2 and f_1 .

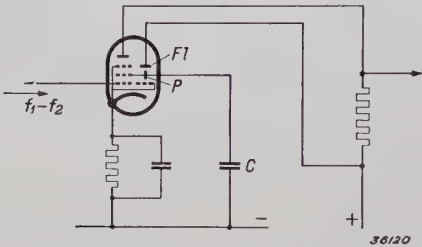


Fig. 7. Connections of the low-frequency pentode EFM 1 which is also arranged as cathode ray indicator. The zero point of the frequency scale is checked by this means.

At higher frequencies (>30 c/s) the screen grid potential may of course no longer increase and decrease with the control grid voltage, since at those frequencies the valve must act as a normal amplifier. A condenser is introduced for this purpose between screen grid and cathode, which forms practically a short circuit for the frequencies mentioned, so that the screen grid potential remains constant.

The shift in the amplitude of the output voltage

For recording frequency characteristics it is desirable that the signal given by the tone generator should remain constant not only in frequency but also in magnitude. The magnitude of the signal is, however, determined by the various plate voltages which may vary considerably due to fluctuations in the mains voltage supply. The temperature variations also during the heating up, etc. may manifest themselves in an undesired way in this respect, since the resistance of the windings of the supply transformer and therefore also the plate voltage hereby changes. In order to limit as far as possible the influence of plate voltage variations on the output of the tone generator, we have employed a compensation connection, the principle of which is given in *fig. 8*. The voltage E obtained from the supply apparatus feeds a neon tube L and a loading resistance R_b , which is formed by

the mixing valve and the two amplifier valves of the tone generator. The voltage V indicated in the figure serves to supply the valve in the generator G_1 (see *fig. 3*). It may be seen that $V = V_0 - iR$,

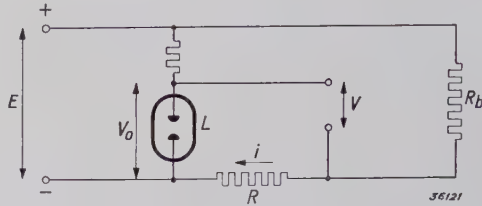


Fig. 8. Compensation connection for obtaining a constant output voltage of the tone generator. E , D.C. voltage given by the supply apparatus, R_b , loading resistance (mixing valve + two amplifier valves). L neon lamp, V plate voltage for the valve in the oscillator G_1 (*fig. 3*).

where V_0 is the voltage on the neon valve and i is mainly the current through the loading resistance R_b . When E increases, i will increase by the amount Δi ; V_0 , however, remains practically constant (it increases by the very small amount ΔV_0 for instance). Thus V varies with

$$\Delta V = \Delta V_0 - R \cdot \Delta i .$$

By choosing a suitable value for R , ΔV can be made more or less negative. Thus while the anode voltage of the three valves indicated by R_b rises with increase of E , that of the first valve falls, and it is clear that these two effects can be made to cancel each other exactly by a suitable choice of R , so that the output voltage of the tone generator as a first approximation is independent of the voltage E , and thus independent of the mains voltage and the temperature. The result thus obtained is reproduced in *fig. 9*. It may be seen that, with mains voltage fluctuations of 10 per cent, the signal of the tone generator only varies 1 per cent in intensity.

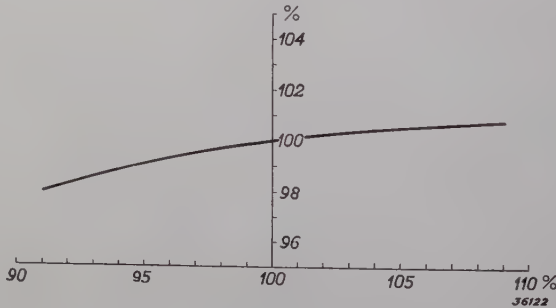


Fig. 9. Shift of the output voltage of the tone generator (vertical axis) upon variations of the mains voltage (horizontal axis).

The use of the tone generator

The voltages which are needed as input voltages in the investigation of different amplifiers may be

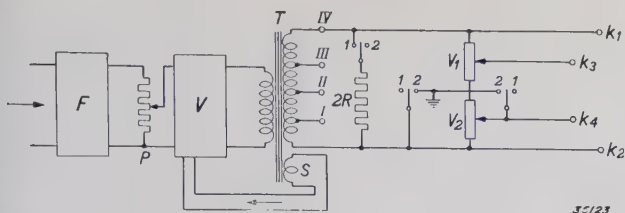


Fig. 10. Connections of the output of the tone generator. With the taps I-IV of the output transformer T the tone generator can be adapted to loading impedances of 1 000, 500, 250 and 5 ohms. S is the winding for inverse feed-back. With the potentiometer P , which is calibrated directly in volts for the tap IV, the intensity of the signal is regulated. On tap IV an attenuator V_1 , V_2 can be connected (this case is shown in the figure). At position 1 of the three switches (operated by a single knob) the two equal attenuators V_1 and V_2 are in series, and a balanced voltage which can be regulated in steps of 10 dB is obtained between the terminals k_3 and k_4 . At position 2 of the switches V_2 is out of connection and k_4 earthed, so that an unbalanced voltage is obtained. Due to the fact that in position 1 the resistance $2R$ (R is the resistance of one attenuator) is connected in parallel with $V_1 + V_2$, the output transformer is loaded with the same resistance (R) in both positions, so that the voltage which can be measured between k_1 and k_2 remains exactly the same.

very different. Therefore in the tone generator the filtered output voltage of the mixing valve is applied to the amplifier *via* a potentiometer (fig. 10). With this potentiometer, which because of its flat frequency characteristic and the slightness of the influence of mains voltage variations, etc., could be calibrated directly in volts, it is possible to set the output voltage given by the tone generator at the desired value. The calibration is valid for adaptation to a loading impedance of 1 000 ohms, the maximum voltage is normally 15 volts in this case. In order to be able to adapt the tone generator approximately to the object being investigated, in the testing of loud speakers, cables, etc., the output transformer is provided with taps for loading impedances of 1 000, 500, 250 and 5 ohms, respectively. The transformer is so constructed that even when the taps are used the frequency characteristic of the tone generator remains practically flat. Furthermore by means of a simple commutation an attenuator can be connected to the output

transformer, and with this the signal can be weakened in steps of 10 dB. The attenuator is so constructed that not only a balanced voltage can be obtained for the investigation of push-pull amplifiers, but also an unbalanced voltage, earthed at one side. This is explained in the text under fig. 10. Fig. 11 is a photograph of the tone generator in which the different knobs for operation of the potentiometer, the attenuator, etc. may be seen.

If higher voltages than 15 volts are needed, as for instance for measuring the deformation of large amplifier valves at full load, or for the investigation of transmitter valves which are used as modulator, the voltage may be taken from the primary winding of the transformer. About 50 volts are then available. By increasing in the manner described (with the condenser G_1 , see fig. 3) the output of the tone generator still more at the expense of somewhat greater distortion, a voltage of 125 volts can even be obtained here.



Fig. 11. The tone generator GM 2 307. On the front panel may be seen the knobs of the rotating condensers (below) with the frequency scales from 0 to 1 000 and from 0 to 15 000 c/s. Above in the middle the cathode ray indicator, to the right and left the knobs of potentiometer, attenuator, etc.

SUBJECTIVE PHOTOMETRY

by J. VOOGD.

535.24

Although it is possible at the present time to carry out the measurements in light technology by an objective physical method, subjective photometry still has very great practical importance. On the basis of investigations carried out in this laboratory an attempt is made to discover which subjective method of measurement offers the best guarantee of obtaining correct results in the measurement of gas-discharge lamps. The use of the filter method is recommended with the flicker photometer and a calculated filter transmission. The filter must be so chosen that the spectral composition (not the colour!) of the filtered light of the comparison lamp corresponds as closely as possible to that of the lamp to be measured, while a group of persons must be chosen as observers at the flicker photometer, such that the average curve of eye sensitivity is well matched with the international eye-sensitivity curve (yellow: blue ratio 0.985).

Due to the development of gas-discharge lamps interest in photometry has increased very much¹⁾. It was found that the results of measurements obtained by visual photometry of these coloured light sources were dependent on the method of measurement used. This fact led, on the one hand, to a new investigation of the basis of visual photometry, while on the other hand it led to attempts to develop objective methods in addition to the visual methods for the determination of the light flux or light intensity of a lamp.

In a previous article in this periodical²⁾ an accurate physical photometer was described, which was constructed in this laboratory, and which has since then been found to be absolutely reliable in practical use. In many laboratories, however, the use of an accurate objective photometer has not yet been adopted. The problems of visual or subjective photometry have therefore retained a practical significance in addition to a theoretical one.

In this article we shall deal with the question which visual method of measurement offers the best guarantee of obtaining correct results. We shall in doing this make use of data which have been obtained in this laboratory during recent years.

The foundation of the subjective photometry of coloured light sources (heterochromous photometry) was laid about 30 years ago, mainly by the work of the American Ives. Ives stated that a useful system for heterochromous photometry must satisfy the following laws:

1) the transitive law:

If $a = b$ and $b = c$, then $a = c$;

2) the additive law:

If $a = b$, then $a + c = b + c$.

From the investigations carried out by Ives in

the first stages of heterochromous photometry, it follows that the results of measurements of every individual observer obey both laws when the work is done under certain photometric conditions. These wellknown conditions of Ives are the following:

- 1) the field of the photometer must be observed within an angle of 2° ,
- 2) the brightness of the field must amount to about 8×10^{-4} stilb.

If these conditions are fulfilled, it is then, according to Ives, a matter of indifference whether a photometer with adjustment to equal brightness or a flicker photometer is used.

Thanks to the validity of the additive law, under the conditions mentioned above every wave-length interval in the spectrum of the radiation emitted gives a contribution to the total brightness which is proportional to the intensity of the radiation in that wave-length interval and to a factor which depends upon the wave length, and which is called the relative eye-sensitivity. Different investigators have determined the eye-sensitivity as a function of the wave length for a number of observers. On the basis of the individual eye-sensitivity curves thus collected, which are mutually quite divergent, an attempt was made in 1924 to determine a curve which might be considered as the average curve of human eye-sensitivity. This curve, known as the international eye-sensitivity curve, has since then become of fundamental significance in heterochromous photometry.

By basing heterochromous photometry upon the international eye-sensitivity curve, and also by the acceptance of the new light unit, the photometric units have obtained physical definition. In order to measure the light intensity K of a light source, the following relation must be determined:

$$K = \frac{\int E_1(\lambda) V(\lambda) d\lambda}{\int E_2(\lambda) V(\lambda) d\lambda} \cdot \dots \quad (1)$$

¹⁾ The photometry of metal vapour lamps, Philips techn. Rev. 1, 120, 1936; The new unit of light intensity, Philips techn. Rev. 5, 1, 1940.

²⁾ Physical Photometry, Philips techn. Rev. 4, 272, 1939.

In this expression $E_1(\lambda)$ is the spectral intensity of the light source to be measured, $E_2(\lambda)$ that of the light source introduced as unit at the wave length λ , and $V(\lambda)$ the international eye-sensitivity at the wave length λ . The integration must be performed over the whole visible spectrum.

Present investigations on the subject of practical visual photometry are for the purpose of finding a method which gives results in agreement with this physical definition. The difficulties thereby experienced are caused by the fact that in the light of later experience it must be doubted whether the foundation of subjective photometry as developed by Ives holds with sufficient accuracy.

Several experiments

When Ives' conditions are satisfied the results of measurement by one observer should be the same when a flicker photometer is used as when a photometer with adjustment to equal brightness is used. This has been tested precisely for several cases.

The light intensity of a gas-discharge lamp was compared with that of a standard lamp whose light had passed through a filter. This filter was so chosen that the colour of the comparison lamp seen through the filter was well matched with that of the gas-discharge lamp. Upon adjustment to equal brightness the accuracy of measurement was not disturbed by the presence of too great a colour difference on the photometer field.

As gas-discharge lamps, a mercury-vapour lamp (HO 1 000) and a sodium lamp (SO 400) were used. In addition the mercury-vapour lamp was also measured through a filter which transmits only the strong green line. For each of these three cases a suitable colour-matching filter was found for the standard lamp. The comparison of the light intensity of the gas-discharge lamp with that of the combination of comparison lamp and colour-matching filter was carried out with different photometers. In the first place we used the Lummer-Brodhun photometers from which the contrast plates had been removed. The field of vision of the photometer is shown in *fig. 1a*. Measurements were also done with the Bechstein photometer with adjustment to equal brightness (also without contrast plates), whose field is shown in *fig. 1b*. Measurements were finally done with a flicker photometer. In all the measurements the area and brightness of the field of vision satisfied Ives' conditions.

From the measurements for one gas-discharge lamp done by one observer we obtained by means of the three photometers, three values of the candle power: K_{LB} , K_B and K_f . These three values should

be equal, except for a slight difference due to errors in measurement. In order to indicate to what degree this is true we have used the ratios K_{LB}/K_f and K_B/K_f .

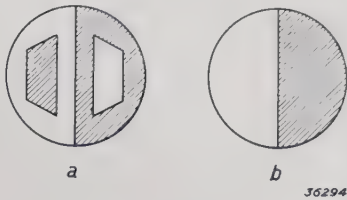


Fig. 1. a) The field of vision of a Lummer-Brodhun photometer.
b) The field of vision of an equal brightness photometer according to Bechstein.
The cross-hatched and non-cross-hatched portions must be adjusted to equal brightness.

In *table I* these ratios are given for each gas-discharge lamp as determined by different observers.

Ob- server	Light source					
	Mercury lamp		Mercury lamp through green filter		Sodium lamp	
	K_{LB}/K_F	K_B/K_F	K_{LB}/K_F	K_B/K_F	K_{LB}/K_F	K_B/K_F
I	1.03	1.00	1.03	0.96	0.99	1.00
II	1.08	1.03	1.03	0.94	1.00	1.01
III	1.05	1.04	1.02	0.98	0.97	1.00
IV	0.99	1.01	1.05	0.97	0.98	0.98
V	1.07	1.02	1.00	0.94	0.99	1.00
VI	1.01	0.98	0.93	0.95	0.97	0.98
VII	1.05	0.99	1.03	0.97	1.02	0.98
VIII	1.04	1.02	—	—	—	—
IX	1.02	1.02	1.06	0.98	0.96	1.02
Aver- age	1.04	1.01	1.02	0.96	0.98 ⁵	0.99 ⁵

In spite of the differences between the individual observers it may be stated that the ratios K_{LB}/K_F and K_B/K_F differ in some cases systematically from the value 1.00. The most favourable case is that of the sodium lamp, where the results agree quite well for the three photometers. In the case of the mercury lamp the lowest light intensity is measured with the flicker photometer; the light intensity measured with the Bechstein photometer corresponds fairly well with this. With the Lummer-Brodhun photometer, on the other hand, it is clear that a higher light intensity is found.

The situation is still different for the mercury lamp seen through a green filter. According to the flicker photometer the candle power here is 2 per cent lower than according to the Lummer-Brodhun photometer, and 4 per cent higher than according to the Bechstein photometer.

In judging these differences it may be noted that it was to have been expected that differences would occur between the measuring results obtained with the flicker photometer and those obtained with the photometer with adjustment to equal brightness. The criteria of adjustment are of quite different character in these cases. It is remarkable, however, that the two photometers with adjustment to equal brightness should exhibit systematic mutual differences. We have not been able to ascertain the cause of this. It is probably significant here that the colour matching, no matter how good it is, can never be perfect. The slight remaining colour difference has a different effect upon the adjustment with the Lummer-Brodhun photometer than on that of the Bechstein photometer. With the Bechstein photometer the colour difference is more clearly observed and the observer remains conscious of the fact that he is adjusting different coloured halves of the photometer field to equal brightness. With the Lummer-Brodhun photometer, on the other hand, this slight colour difference is scarcely noticed during the adjustment. This is probably due to the greater subdivision of the field of vision of this photometer.

From the above described experiments it is found in any case that divergent results can be obtained under Ives' conditions in photometry with different photometers. The question therefore arises as to whether the transitive and additive laws are valid in the measurement with each of these photometers, and if this is true, whether different eye-sensitivity curves are obtained for a single observer with different photometers. Similar difficulties have been encountered in other laboratories. The investigations on this subject are by no means complete. The fact that there is uncertainty in this respect, however, necessitates great care in the application of visual photometry for the determination of the physically defined photometric quantities.

Which photometric method offers the best guarantee of a correct and accurate result?

As we have seen in the foregoing, fulfilment of Ives' conditions offers no sufficient guarantee that the transitive and additive laws are valid. Nevertheless, the validity of these laws must be considered a primary requirement for obtaining correct results by means of a photometric arrangement.

Photometry with adjustment to equal brightness has the great disadvantage that reproducible measurements are practically impossible when there is an appreciable colour difference. Therefore it is extremely difficult to control the validity of the

transitive and additive laws directly in measurement with such a photometer. But even if it were possible to assume that the transitive and additive laws are valid, there still remains the question of whether the eye-sensitivity curve of the observer corresponds sufficiently well with the international eye-sensitivity curve. This also can only be controlled by a time-consuming and essentially inaccurate investigation.

In both respects the flicker photometer offers great advantages. Since one can use this photometer even in the presence of large colour differences, a direct control of the transitive and additive laws is immediately possible. As far as our experience goes these laws are found to be satisfied exactly. For the same reason it is quite easy to obtain information about the eye-sensitivity curve of an observer. It is possible to form in this way a group of observers whose average more or less agrees with the international eye-sensitivity curve.

A simple method of doing this has already been worked out by Ives and Kingsbury. They give a method of preparing two different coloured light sources (a blue and a yellow one) which must have exactly the same intensity for an observer with a normal eye-sensitivity curve³⁾. If an individual observer is allowed to determine the ratio of the light intensities (yellow: blue) with the help of a flicker photometer, he will in general find a result which differs from 1.00. If, however, a number of observers is chosen so that the average yellow-blue ratio of the whole group is exactly equal to 1.00, then according to Ives and Kingsbury the average shape of the eye-sensitivity curve of all the observers may be considered as normal. Later measurements have changed this value somewhat. In order to obtain the best agreement with the international eye-sensitivity curve the average yellow-blue ratio of the group of observers must not be exactly equal to unity but to 0.984⁴⁾.

³⁾ The coloured light sources are composed of a carbon filament lamp and a coloured filter. The carbon filament lamp must burn at a colour temperature of 2077° K. The yellow filter consists of a solution of 72 grams of potassium bichromate per litre of solution; the blue filter of a solution of 57 grams of copper sulphate per litre of solution. Both filters are used in cuvettes with an internal thickness of 1 cm.

⁴⁾ It cannot yet be concluded how accurately the average eye-sensitivity curve of a group of observers formed in this way agrees with the international eye-sensitivity curve. In addition to accidental deviations which are determined by the choice of the observers, systematic deviations are not held impossible. Various investigators are now working on this question. From the result of these investigations will depend whether the method of direct flicker photometric comparison of the gas-discharge lamp with the standard lamp presents the possibility of obtaining correct results.

It is now important to know to what degree the result of measurement by an observer can be determined by the yellow:blue ratio. For this purpose the candle power of a mercury lamp was compared with that of a gas-filled incandescent lamp by a number of observers with a known yellow:blue ratio. From the individual results for the candle power ratio the average for the group of observers was formed. The deviation of the individual results from this average is plotted in *fig. 2* as a function

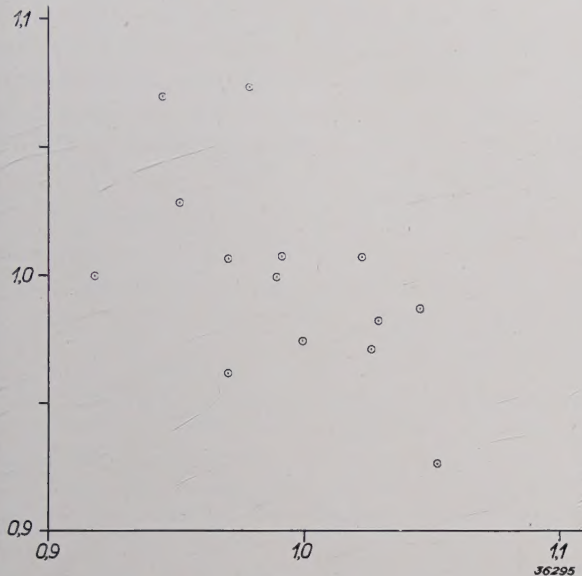


Fig. 2. For each of a number of observers the ratio measured by him between the intensities of a mercury lamp and a gas-filled incandescent lamp is plotted as ordinate, while as abscissa the value is plotted of his "yellow-blue" ratio. The average value of the ordinate for the whole group is set equal to 1.00.

of the yellow:blue ratio. The points obtained show indeed a general tendency, but it is evident that fairly divergent values of the candle power of the mercury lamp can be measured by different observers having the same value of the yellow:blue ratio. This is to be ascribed to the fact that the eye-sensitivity curves of different observers may be of relatively strongly diverging shapes, even when the yellow:blue ratio is the same. It is thus possible for example that the maximum should lie at the correct wave-length of $5550 \text{ \AA}$, but that the curve falls too rapidly or too slowly toward the red or blue. In comparing a gas-discharge lamp with an ordinary incandescent lamp, where the spectral energy distributions of the light curves to be compared are very different, such differences may be very significant.

In order to combat this source of uncertainty the obvious method would be to match the spectral energy distribution of the comparison lamp by means of a filter to that of the gas-discharge lamp

to be measured. If it were possible to make the spectral distributions of the two light sources exactly the same, it would then be a matter of indifference, as far as the photometric adjustment is concerned, what the shape of the eye-sensitivity curve of the observer was. In practice only a relatively rough matching of the spectral energy distribution of an incandescent lamp to that of a gas-discharge lamp can be obtained with a filter. It is found nevertheless that by this rough matching the possible difference between the adjustments of different observers with the same yellow:blue ratio can be considerably reduced, as may be seen when *fig. 3* is compared with *fig. 2*. The possible difference between the average adjustment of a group of observers with an average yellow:blue ratio of 0.985 and the adjustment according to the international eye-sensitivity curve is obviously also decreased at the same time.

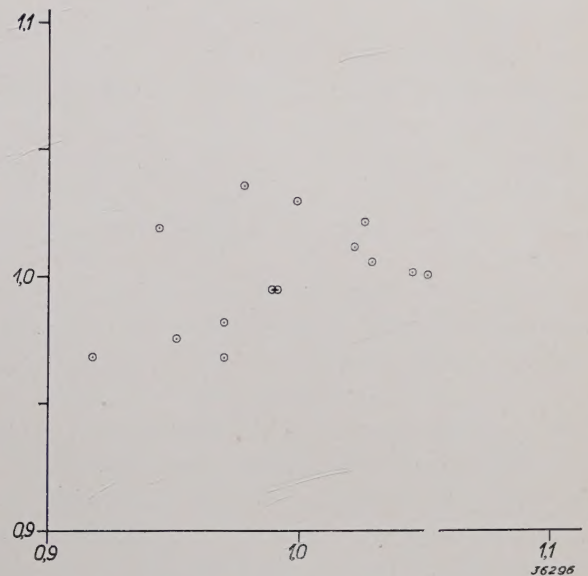


Fig. 3. Same as *fig. 2* for the case where the spectral energy distribution of the comparison lamp is adapted to that of the mercury lamp by means of a filter which transmits only the wave length region from $5300 \text{ \AA}$ to $5900 \text{ \AA}$. The intensity ratios measured by the different observers between the mercury lamp and the comparison lamp are now much less divergent.

If one now attempts to apply this concept in practice, one arrives at the so-called filter method in which the determination of the intensity of a gas-discharge lamp takes place in two stages. In the first stage the ratio K_g/K_f is determined between the candle power of the gas-discharge lamp and the candle power of the filtered comparison lamp in the second stage the ratio K_f/K_0 between the intensities of the filtered and the non-filtered light of the comparison lamp. The required candle power of the gas-discharge lamp is then obviously:

$$K_g = \left(\frac{K_g}{K_f} \right) \left(\frac{K_f}{K_0} \right) K_0.$$

The first factor can, as stated above, be measured with sufficient accuracy with the flicker photometer, if the observers are so chosen that the average yellow-blue ratio has a value of 0.985. The second factor, the transmission of the filter could not, however, be determined accurately enough by this method, since the spectral composition of the filtered and the non-filtered radiation of the electric lamp differ too widely from each other. It is therefore better to measure the transmission of the filter objectively. This can for example be done by measuring the spectral transmission of the filter and calculating from this with the help of the known intensity distribution of the comparison lamp and of the international eye-sensitivity curve the visual transmission τ . This amounts to

$$\tau = \frac{\int E(\lambda) \tau(\lambda) V(\lambda) d\lambda}{\int E(\lambda) V(\lambda) d\lambda}.$$

where $E(\lambda)d\lambda$ is the intensity of the comparison lamp in the wave length interval $\lambda \rightarrow \lambda + d\lambda$, $\tau(\lambda)$ the spectral transmission and $V(\lambda)$ the relative eye-sensitivity. If an objective photometer is available the quantity τ can of course be determined by direct measurement.

We thus reach the conclusion that for visual photometry the best method is the filter method with objectively determined filter transmission and use of a flicker photometer for the comparison of the gas-discharge lamp with the filtered light of the standard lamp. This method of measurement has been tested in this laboratory by comparing its results with those given by the previously described objective photometer in the same measurements. From the results we may conclude that the systematic errors of this method in the case of mercury and sodium lamps are not greater than 1 per cent.

Appendix

The use of the flicker photometer for gas-discharge lamps burning on alternating current

Until now we have tacitly assumed that the intensity of the lamp being measured is constant during the measurement. In the case of gas-discharge lamps, however, this is generally not the case; such lamps are usually operated with alternating current, and the light intensity in the first approximation exhibits the same variation as the absolute value of the current. If one looks at the lamp or at a surface brightly illuminated by the lamp the flicker can scarcely be seen, since the eye cannot follow the rapid light changes. If, however, the lamp is measured with a flicker photometer, these fluctuations lead to stroboscopic effects which make the adjust-

ment of the photometer difficult, and, moreover, cause doubt as to whether or not the adjustment is indeed correct, i.e. whether it indicates the average value of the light flux to be measured.

For this reason the flicker photometer is often replaced by a photometer with adjustment to equal brightness for the measurement of A.C. lamps, in spite of the difficulties which we have outlined above. If the matching of the spectral composition of the light of the comparison lamp to that of the lamp to be measured were perfect, there would be no objection to this, since in the measurement of identical light sources the adjustment is independent of the photometric method used. In practice, however, due to the limited choice of types of filters, the matching is far from perfect, and due to this, photometry with the equal brightness photometer has still other objections in addition to the uncertainties explained above.

The limited choice of filter types particularly has the result that the filtered light with the best spectral matching which can be attained differs considerably in colour from the lamp to be measured, which is decidedly not permissible with an equal brightness photometer. Thanks to the fact that two lights with the same colour by no means need have the same spectral composition, it is nevertheless still possible to find a filter which gives a practically perfect colour matching; this filter will, however, in general by no means lead to the best possible matching in the spectral energy distribution.

An example of this is encountered with the mercury lamp. The blue and violet radiation of this lamp contribute almost nothing to the light flux, but they affect the colour very strongly. The colour adaptation of the comparison lamp can best be realized with the help of filters which absorb in the red. The filtered light then contains considerable blue-green in contrast to the mercury light. From the point of view of adaptation of the spectral energy distribution, it is better to neglect the blue and violet radiation of the mercury lamp and to choose a filter which gives only an adaptation to the green and yellow mercury lines, by transmitting the light between 5 300 Å and 5 900 Å, for example. Such a filter could not be used with a photometer for adjustment to equal brightness. When the filter method is used with the flicker photometer, such a filter can nevertheless be employed.

The requirement of a very close colour adaptation for the adjustment to equal brightness has, moreover, another practical disadvantage. In practice lamps are often encountered whose spectral energy distribution varies relatively little, while the colour is clearly different. For all these types of lamps different filters would have to be used. If a flicker photometer is used fewer filters are needed.

Summarizing, we may therefore say that the use of a photometer with adjustment to equal brightness has three disadvantages. In the first place the result depends upon the type of photometer used; in the second place it is often necessary to make the adaptation of the spectral energy distribution of the comparison lamp to that of the gas-discharge lamp poorer than when it is unnecessary to consider the colour adaptation, so that the result becomes more dependent on the individual eye-sensitivity curve of the observer. In the third place, for the same number of types of lamps to be measured a larger number of filters is needed. Over against these disadvantages is the advantage that the light fluctuations of gas-discharge lamps operated with alternating current are not disturbing.

In order to ascertain whether this advantage is of decisive importance, the reproducibility was investigated in the measurement of different gas-discharge lamps operating on alter-

nating current according to the filter method with a photometer for equal brightness and with the flicker photometer. It was found that the adjustment of the flicker photometer was just as reproducible as that of the equal brightness photometer in spite of the appearance of beats. Moreover, it could be determined in a different way than with the flicker photometer

the true average value of the light intensity of the lamp was actually found within the limits of error of the measurement. We therefore conclude that the objections to the photometry of alternating current lamps with the flicker photometer are without foundation.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

- 1494:** J. H. de Boer and J. D. Fast: Electrol-
ysis of solid solutions of oxygen in metallic
zirconium (*Rec. trav. chim. Pays-Bas* **59**,
161-167, Febr. 1940).

The lattice constants and the density of zirconium are determined with varying amounts of dissolved oxygen. According to the results the oxygen atoms are situated in the interstices of the zirconium lattice. At high temperature they possess a great mobility in the lattice. Under the influence of an electric field the oxygen moves through the lattice as a negative ion, so that the oxygen concentration (and thereby also the electrical resistance) increases at the anode end and decreases at the cathode end.

- 1495*:** M. J. O. Strutt: Modern multigrid electronic valves. Construction, Functioning, Properties, Electrophysical Foundations. Second enlarged and improved edition, Springer, Berlin 1940, 283 pages. (German language).

A review of the first edition was given under **1279*** and **1350***. The second edition also takes into account the newest types of valves developed since the publication of the first edition.

- 1496:** A. Bouwers: On the behaviour of slow neutrons in water and paraffine (*Physica* **7**, 193-198, Mar. 1940).

The yield from a powerful source of neutrons can be measured in a simple way with the help of a very thin detector for slow neutrons, which is placed in a substance rich in hydrogen surrounding

the source. Two quantities are discussed which are important for the interpretation of the experiments: the average length of trajectory δ of a neutron in this thin detector, and the average number of collisions before the neutron is captured. In the case of the number of collisions, the reflection coefficient (albedo) of a smooth limiting plane plays a part; the value of this coefficient could be determined by elementary considerations.

- 1497:** W. de Groot and K. F. Niessen: Note on the "albedo" of a hydrogenated substance for slow moving neutrons (*Physica* **7**, 199-204, Mar. 1940).

O. Halpern, R. Lüneberg and O. Clark (*Phys. Rev.* **53**, 173, 1938) have given for the reflection coefficient β of a hydrogenated substance for slow moving neutrons, the so-called albedo, the formula: $\beta = 1 - 2.31/\sqrt{N}$, where N is the average number of collisions which a neutron undergoes before its capture. By a process of estimation of the second term, this formula is extended to:

$$\beta = 1 - 2.31/\sqrt{N} + 2.86/N.$$

- 1498:** N. Warmoltz: Some properties of an anchored cathode spot of a mercury arc at low pressure (*Physica* **7**, 209-216, Mar. 1940).

The cathode spot of a mercury arc, which generally executes a dancing motion on the surface of the mercury, can be anchored by immersing in the pool of mercury a metal electrode (the "anchor"). For different forms of anchor the velocity of evaporation of the mercury is determined, and it is ascertained how the maximum current, at which the cathode spot still remains on the anchor, depends upon the temperature. The experiments confirm the impression that it is very important for the anchorage that the anchor should be wetted by the mercury.

*) An adequate number of reprints for the purpose of distribution is not available of those publications marked with an asterisk. Reprints of other publications may be obtained on application to the Natuurkundig Laboratorium, N.V. Philips' Gloeilampenfabrieken, Eindhoven (Holland), Kastanjelaan.

- 1499:** J. A. M. van Liempt and J. A. de Vriend:
A new method for adjusting synchronizers,
also suitable for testing focal-plane shutters
(Physica 7, 217-224, Mar. 1940).

A new method is described for the adjustment of the synchronizer necessary for the simultaneous operation of shutter and flash lamp. As measuring instrument a falling plate oscillograph is used, whereas in the apparatus previously described a cathode ray oscillograph had to be used. Additional advantages of the new apparatus are that it can be calibrated without wasting flash lamps, and that it can also be used in testing focal-plane shutters.

- 1500:** J. A. M. van Liempt and J. A. de Vriend:
A clarification of the conception of certain
quantities in light technology with reference
to photo-flash lamps (Physica 7, 255-264,
Mar. 1940) (Original in German).

A survey is given of the commonly used constants for photo-flash lamps, such as the total flash time, practical flash time, 50% flash time, median time, median light intensity and photographic lumens-second. The existing definitions of these quantities are criticized and partially replaced by new definitions which are better adapted to practical use.

- 1501:** J. F. Schouten: The residue, a new component in subjective sound analysis (Proc. Kon. Akad. Wet. A'dam 43, 356-365, Mar. 1940).

It has long been known, that when the ear picks up a series of harmonic tones in which only the fundamental is missing, an impression is received as if this fundamental were present in the sound observed, and even as if it were fairly intense. Previous experiments have convinced the author that this "missing" fundamental is not observed because, as is often assumed, of non-linear deformation in the ear. From the experiments here described, which are a repetition with the optical syren of experiments done by Seebeck nearly 100 years ago, it becomes reasonable to assume that the colaboration of those higher harmonics which are no longer observed individually by the ear (above the twelfth, for instance), and which the author proposes to call the "residue", is the cause of the observation of the "missing" fundamental. This concept makes necessary a modification of Ohm's acoustic law, which was suspected by Seebeck, but not clearly expressed by him. Besides the fact that it gives a very acceptable explanation of the fine experiments of Seebeck which were repeated, the theory of the residue is found to be of use in other acoustic problems also, several

of which the writer promises to deal with in the future.

- 1502*:** F. A. Heyn: De wisselwerking tusschen neutronen en materie (II) (The reaction between neutrons and matter) (Ned. T. Natuurk. 7, 107-123, Feb. 1940).

The main subject of part I was the reaction between fast electrons and matter. In this communication (II) the reaction is discussed between matter and slow neutrons which is of great importance due to the appearance of the resonance of atomic nuclei. Following several theoretical remarks about the effective diameter of the atomic nucleus for the capture of a slow neutron, in which it is shown that for all nuclei there is a region in which the diameter is inversely proportional to the speed of the neutron, methods are indicated of obtaining low-speed neutrons (with a velocity of the order of thermal velocity). With the help of these, resonance levels have been determined which are summarized in a table. The width of these levels, which has been determined in certain cases, is discussed, as well as their Doppler broadening. A table is given summarizing the effective diameters for capture and scattering of slow neutrons. In connection with this several observations are given on the scattering power of matter which cannot be explained from the scattering power of the atomic nuclei alone.

- 1503:** J. L. Snoek: Over de inwendige demping van vaste stoffen (On the internal damping of solid substances). (Ned. T. Natuurk. 7, 133-146. Mar. 1940).

Several quantities which are measured of the internal friction in solid substance are defined and their mutual relations considered. An important cause of the internal friction is the local heat currents in the material, i.e. the so-called thermoelastic effect. In many cases this is almost exclusively responsible for the damping observed. These heat currents may extend over relatively great distances (for instance, the thickness of transversally vibrating rods) or over much smaller distances (for instance, the distance between two adjacent crystallites). In all cases the losses are at a maximum at a frequency $\nu_k = cDa^{-2}$, where c is a constant of the order of magnitude 1, D the heat diffusion constant (coefficient of heat conductivity) and a the average distance between regions of opposite temperature fluctuation (for transversally vibrating rods this is the diameter of the rod, for longitudinally vibrating rods an estimation can be made in another way).